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CONCEPT FOR IMPROVING AIR QUALITY MONITORING IN ARMENIA

Final Draft under LoA with UNDP

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1 INTRODUCTION

Air quality monitoring concept

Within the EU-UNDP Project No. 00115652 “EU4Climate” the Environment Agency Austria (EAA, Umweltbundesamt) was conducted a contract to develop a "A general concept for improving air quality monitoring in Armenia based on requirements arising from the "Comprehensive and enhanced Partnership Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part, and the Republic of Armenia, of the other part" (CEPA agreement). For air quality, the CEPA agreement aims at harmonising the Armenian legislation towards the European Air Quality Directives.

2 ANALYSIS OF THE LEGAL FRAMEWORK

2.1 Analysis of the legal framework in Armenia for environmental monitoring

2.1.1 Law on Air Protection

Draft law to be adopted soon

Currently, the draft Law on Air Protection is close to being finalised and adopted. The draft Law on Air Protection is not a direct implementation of EU AAQD, as it is required for EU Member States, but provides the basis for further, more detailed provisions. Therefore, a number of provisions still have to be implemented in future legal acts (Juelich 2020). This includes the following issues regarding AQ monitoring:

- Definitions of main concepts (Article 4 of the draft Law on Air Protection);
- Delimitation of zones and agglomerations (Article 5);
- Reporting / information requirements (Article 5);
- Criteria, regulations, for AQ monitoring; AQ standards including limit and target values (Chapter IV, Article 10);
- AQ monitoring in detail (Article 17).

2.1.2 CEPA

Partnership agreement

The "Comprehensive and enhanced Partnership Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part, and the Republic of Armenia, of the other part" (CEPA) was published on 26 January 2018 in the Official Journal of the European Union[1] L 23/4. Article 46 of Chapter 3 of the CEPA lays down in general that:

"*1. Cooperation shall aim at preserving, protecting, improving and rehabilitating the quality of the environment, protecting human health, utilising natural resources in a sustainable manner and promoting measures at international level to address regional or global environmental problems, including in the areas of:*

(a) environmental governance and horizontal issues, including strategic planning, environmental impact assessment and strategic environmental assessment, education and training, monitoring and environmental information systems, inspection and enforcement, environmental liability, combating environmental crime, transboundary cooperation, public access to environmental information, decision-making processes, and effective administrative and judicial review procedures;

(b) air quality;"

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.023.01.0004.01.ENG

The CEPA also calls for cooperation between the countries to develop strategies (including timetables, milestones, responsibilities, financing) *inter alia* for air quality.

Provisions for air quality

Annex III to chapter 3 of the CEPA lays down the directives and provisions *inter alia* regarding air quality. The relevant provisions for an air quality monitoring system are the following ones:

- Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe
  - Adoption of national legislation and designation of competent authority/ies
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 4 years of the entry into force of this Agreement.
  - Establishment and classification of zones and agglomerations (Articles 4 and 5)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 7 years of the entry into force of this Agreement.
  - Establishment of upper and lower assessment thresholds and limit values (Article 5 and 13)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 7 years of the entry into force of this Agreement.
  - Establishment of a system for assessing ambient air quality in relation to air pollutants (Articles 5, 6 and 9)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 8 years of the entry into force of this Agreement.
  - Establishment of air quality plans for zones and agglomerations where levels of pollutants exceed limit value/target value (Article 23)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 8 years of the entry into force of this Agreement.
  - Establishment of short-term action plans for zones and agglomerations in which there is a risk that alert thresholds will be exceeded (Article 24)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 8 years of the entry into force of this Agreement.
  - Establishment of a system to provide information to the public (Article 26)
    - Timetable: those provisions of Directive 2008/50/EC shall be implemented within 6 years of the entry into force of this Agreement.
- Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air
  - Adoption of national legislation and designation of competent authority/ies

    - Timetable: those provisions of Directive 2004/107/EC shall be implemented within 5 years of the entry into force of this Agreement.
- Establishment of upper and lower assessment thresholds (Article 4(6)) and target values (Article 3)
    - Timetable: those provisions of Directive 2004/107/EC shall be implemented within 6 years of the entry into force of this Agreement.
- Establishment and classification of zones and agglomerations (Articles 3 and 4(6))
    - Timetable: those provisions of Directive 2004/107/EC shall be implemented within 6 years of the entry into force of this Agreement.
- Establishment of a system for assessing ambient air quality in relation to air pollutants (Article 4)
    - Timetable: those provisions of Directive 2004/107/EC shall be implemented within 8 years of the entry into force of this Agreement.
- Taking measures in order to maintain/improve air quality in respect of the relevant pollutants (Article 3)
    - Timetable: those provisions of Directive 2004/107/EC shall be implemented within 8 years of the entry into force of this Agreement.

Summary of most relevant topics

To summarise the topics most relevant for this AQ monitoring concept:

- the adoption of national legislation and designation of competent authority/ies should take place until 2022;
- classification of zones and agglomerations until 2025;
- upper and lower assessment thresholds and limit values until 2025;
- the system for assessing ambient air quality in relation to air pollutants should be in place until 2026;
- the system to provide information to the public should be established until 2024.

2.1.3 HMC Charter

Provisions for air quality monitoring

The "Hydrometeorology and Monitoring Center" State Non-Commercial Organization[2] ("HMC" SNCO) is a non-commercial organization by the state, which was established by the N 81-N decree (January 30, 2020) of the Government of the Republic of Armenia. HMC merges the "Environmental Monitoring and Information Center", "Forest Monitoring Center" and the "Hydrometeorology and Atmospheric Impact Services" SNCOs. HMC is the legal successor of these centres. The relevant provisions of N 81-N decree for air quality monitoring are the following ones:

- *10. Main subject of activity and objectives of the Organization shall be:*

[2] The charter of HMC is available on the website: http://armmonitoring.am/page/13

  - *1) promoting the rational use of the components of the environment – atmospheric air* [...] *by observing the components of the environment and the factors affecting them, creating sufficient data to assess the situation, registering, analyzing, providing and maintaining thereof;*
- *11. The activity issues of the Organization shall be:*
  - *1) ensuring the monitoring of the environment planned and in accordance with the international standards and integrated indicators* [...];
  - *2) ensuring the observations on the environmental* [...] *phenomena and processes, the receipt of reliable information on their state, the download of the received information in integrated databases (fund) and the provision of information to state bodies, NGOs and the public;*
  - *4) ensuring the process of the improvement of systems of environmental* [...] *activities, the development of the observation networks and logistics base, the investment in modern technical means and information technology, the exploitation of technical means and the current repair, the verification and calibration of professional checking and measurement devices and other measuring instruments;*
- *12. The functions of the Organization shall be:*
  - *1. implementation of environmental monitoring, including:*
    - *a) implementation of observations on atmospheric air pollution, physical impacts on atmospheric air, natural phenomena occurring in the atmosphere, as well as climate change, ozone-depleting substances and other anthropogenic impacts and phenomena;*
  - *3. creating and maintaining an integrated database (fund) of environment, including natural resources (excluding mineral resources)* [...] *phenomena and processes,*
  - *4. collecting and analyzing data received as a result of monitoring of environmental* [...] *activities, and providing information to state bodies, NGOs and the public;*
  - *5. notifying of projects of state significance for active influence on environmental monitoring* [...] *atmospheric phenomena, as well as about a threat to the protection of population and economy, of citizens' life and their property from the state of environment* [...] *phenomena due to high level of pollution,*
  - *6. partaking in development works of legal acts on environmental monitoring,* [...] *and active influence on atmospheric phenomena,*
  - *7. participating in implementation of environmental* [...] *monitoring programs of international and regional significance, fostering and developing comprehensive information exchange and integrated regional international systems,*
  - *8. fulfilling works arising from the international obligations and undertaken by the Republic of Armenia, including preparation of national reports and messages.*
- *13. The Organization shall carry out the following types of activity:*
  - *1) carrying out laboratory tests and analyses;*

- *5) providing relevant information services and atmospheric radiolocation observations;*
- *6) implementing GIS and remote sensing research.*

To summarise, the HMC is responsible to monitor air quality in accordance with international standards and to inform state bodies, NGOs and the public.

2.2 Legislative requirements for the creation of state information systems

To be elaborated further, depending on the specific regulatory needs for the implementation in Armenia.

3 LIST OF ENVIRONMENTAL MONITORING SYSTEM USERS

Users of an environmental monitoring systems are typically the following ones:

- Ministries and governmental organizations:
  - Ministry of Health
  - Ministry of Emergency Situations
  - Ministry of Territorial Administration and Infrastructure with local bodies
  - Environmental Protection and Mining Inspection Body of the Republic of Armenia
  - Statistics Committee
- Stakeholders:
  - Industrial operators
  - Consultants;
  - …
- International organizations:
  - EMEP
  - GAW
- NGOs
- Public
- Newspapers, television, radio broadcaster
- Social media
- Smartphone application developer

4 ASSESSMENT OF THE CURRENT SITUATION

4.1 Hydrometeorology and Monitoring Center 2009-2017

Air quality monitoring in Armenia has undergone significant changes during the last 2-3 decades. The air quality monitoring network was quite extensive during the Soviet Union, but was significantly impacted by the collapse of the Soviet Union (EEA 2011).[3]

HMC established

A "Hydrometeorology Monitoring Center" (State Non-Commercial Organisation – SNCO) was established under the Government of the Republic of Armenia in 2020 as a successor of the "Environmental Monitoring Information Center" (EMIC), "Hydrosphere Service of Active Influence on Events" and "Forest Monitoring Center".

Database

A database existed in HMC and it was populated with air quality monitoring data from 7 cities of Armenia (Yerevan, Gyumri, Vanadzor, Alaverdi, Hrazdan, Tsaghkadzor and Ararat). The data was obtained from automated methods and passive samplers installed throughout the country. In addition, chemical analysis of certain indicators in precipitations is performed. Table 1 below shows the parameters that are monitored by automated stations, non-automated stations, as well as passive samplers.

Table 1: Air quality parameters and measurement methods.

Not-automated method	Automated method	Passive sampling
Dust	Carbon monoxide	Sulphur dioxide
Sulphur dioxide	Sulphur dioxide	Nitrogen dioxide
Nitrogen dioxide	Nitrogen oxides (monoxide, dioxide, total oxides)	
Nitrogen oxide	Ground-level ozone	
Ground-level ozone		
Aromatic hydrocarbons		

Until 2009 for most of the parameters, the samples were collected 3 times a day; since 2010, the daily average was obtained.

HMC website

In addition to the database, the website of the HMC[4] used to provide, weekly graphs with daily data, average monthly data, summarised data from passive

[3] "Armenian country report" from September, 2011 by the European Environment Agency; https://wedocs.unep.org/bitstream/handle/20.500.11822/9443/-Armenia_Country_Report_EEA-2011Armenia_Country_Report_EEA_2011.pdf.pdf?sequence=3&amp%3BisAllowed

[4] http://www.armmonitoring.am

samplers, as well as detailed information from the air quality monitoring stations.

On-line data

The on-line data provided is compared to the corresponding Maximum Allowable Concentrations (MAC) and for better visualisation provides also graphics.

- The central laboratory (no ISO 17025 accreditation yet), where all the data gets send and accumulated is in Yerevan. There are 15 computers, on which Windows 10 and Windows XP, MS Office 2007 and 2019, including Excel is installed.
- There are no IT system managers, software developers, nor data management staff.
- The central laboratory in Yerevan (the second laboratory is located in the city of Vanadzor) used a database created using MySQL and an application, created in C++, operating in Linux®, open source operating system (OS).
- Linux is used only for the MySQL database.
- The data from automatic analysers was stored as 10 minutes averages in the monitoring stations and then sent to the database in the laboratory.
- This database is not in use anymore, but used as an archive; in addition, there is no equipment available to make use of the database. No financial and human resources are available to use it again. Nevertheless, in principle the data might be transferred to a new database if the data was stored properly.
- Currently, all the air quality is obtained manually and stored in Excel files. The data is transferred via internet or phone.
- Hydromet has an IT department and database (s?) for all the meteorological data. An option is to explore if a cooperation is possible regarding databases and IT services.

Further exchange at operational level regarding IT personnel and details of technical capacities will be needed.

4.2 Analysis of the current state of environmental monitoring facilities

4.2.1 Current air quality monitoring stations

Current AQ network

Air quality (AQ) monitoring in the Republic of Armenia is done by the Hydrometeorology and Monitoring Center (HMC), which is a non-commercial organization under the Ministry of Armenia. The AQ network consists of 15 active sampling stations (Table 2), one regional background station within the EMEP programme[5] to monitor transboundary air pollution and 214 passive sampling points. Figure 1 shows the air quality monitoring stations in Yerevan[6].

Table 2: Air quality monitoring stations in the Republic of Armenia

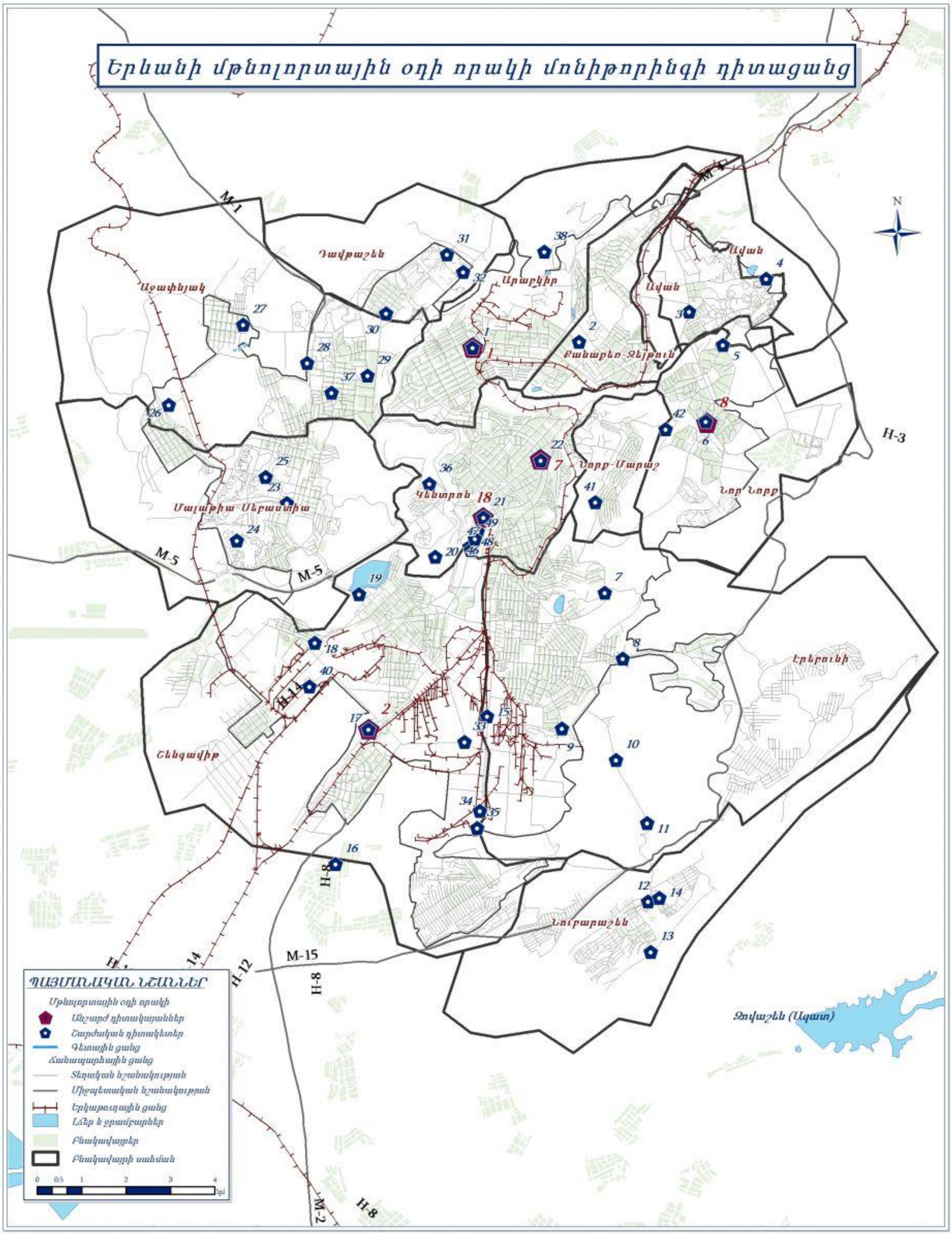
Marz	City	Number of station	Geographical coordinates	
			Latitude	Longitude
Yerevan	Yerevan	1	40.20602	44.50543
		2	40.12840	44.47842
		7	40.18342	44.52350
		8	40.19103	44.56747
		18	40.17154	44.50842
Ararat	Ararat	1	39.84528	44.70159
Kotayq	Hrazdan	1	40.54867	44.77135
	Tsaghkadzor	1	40.53748	44.71850
Shirak	Gyumri	1	40.80620	43.84835
Lori	Alaverdi	1	41.09881	44.64245
		2	41.09145	44.65378
		3	41.09944	44.67538
	Vanadzor	1	40.80320	44.51606
		2	40.80468	44.49322
		3	40.81444	44.47146
Aragatsotn	Amberd (EMEP station)	1	40.384231	44.260042

[5] Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe, https://www.emep.int/

[6] http://armmonitoring.am/page/61

Figure 1: Air quality monitoring network in the Yerevan City (active sampling: red dots, passive sampling: blue dots)

Air quality stations in Yerevan



Source: HMC

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Monitoring in Yerevan

The following figures show some photos of the current air quality monitoring stations in Yerevan.

The locations of the stations itself look very reasonable for an urban background station (station no 1, 2) and urban traffic station (no 7, 8, 18), even though, station no 7 and 18 might be too close to major junctions. Hence, these stations might be moved down the road according to the European AAQD micro-scale siting criteria. However, the buildings and the infrastructure (inlets, electricity, air conditioning) themselves are worn down and should be replaced.

Yerevan air quality station no 1

Source: HMC

Yerevan air quality station no 2

Source: HMC

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Yerevan air quality station no 7

Source: HMC

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Yerevan air quality station no 8

Source: HMC

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Yerevan air quality station no 18

Source: HMC

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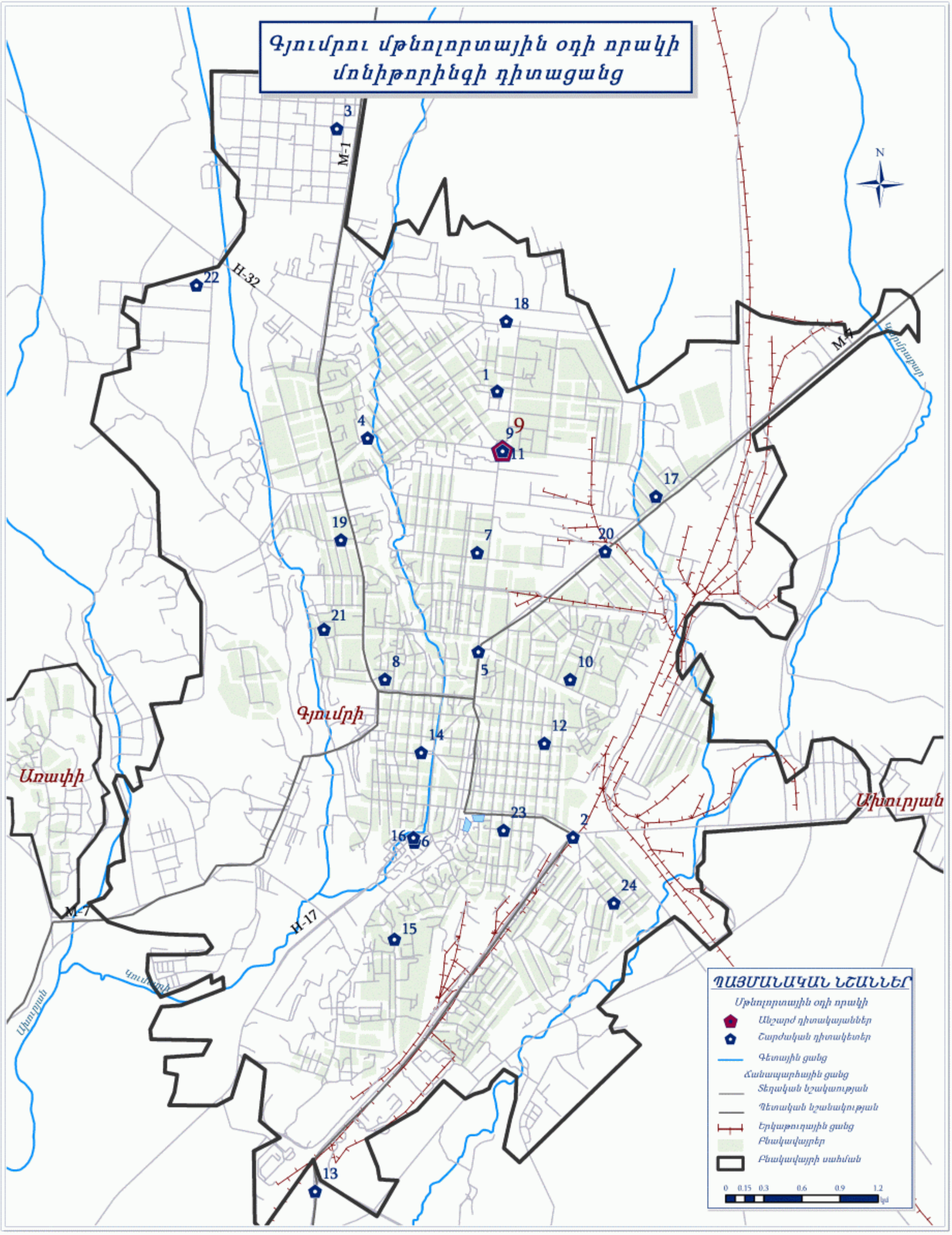
Figure 2 shows the locations of the air quality monitoring stations in Gyumri.

Figure 2: Air quality monitoring network in Gyumri (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring stations in Gyumri



Source: HMC

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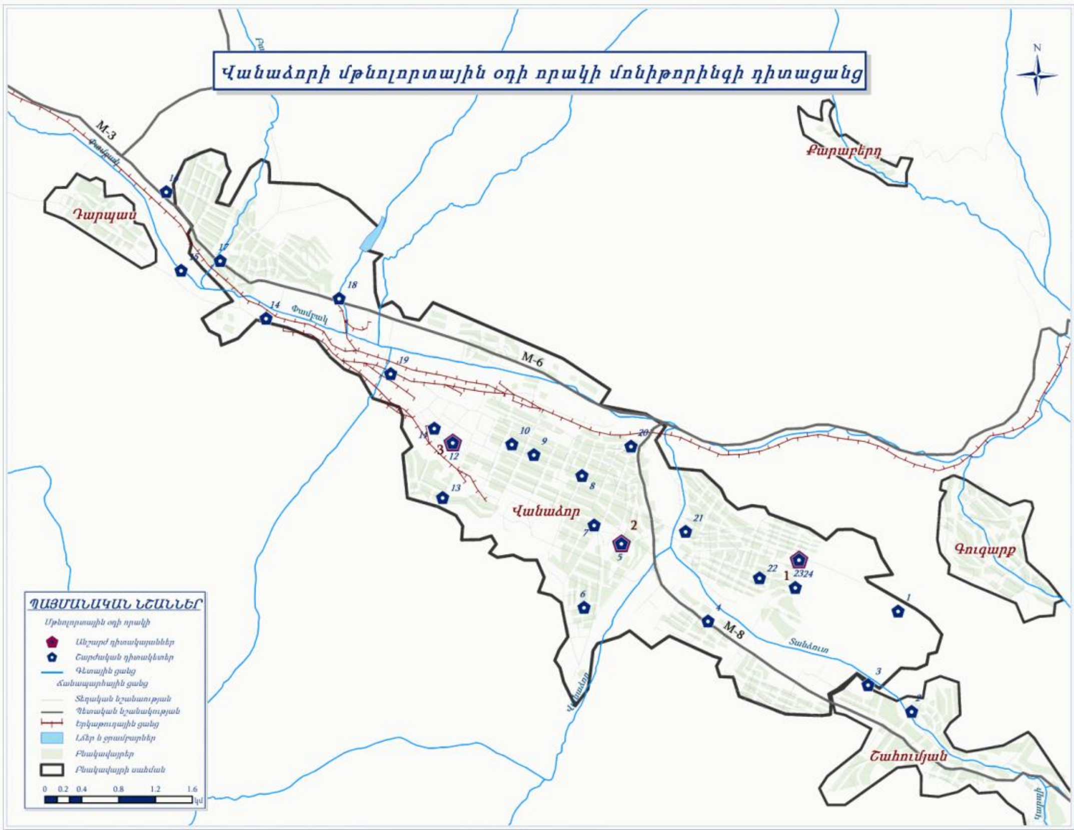
Figure 3: Air quality monitoring network in Vanadzor (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring network in Vanadzor



Source: HMC

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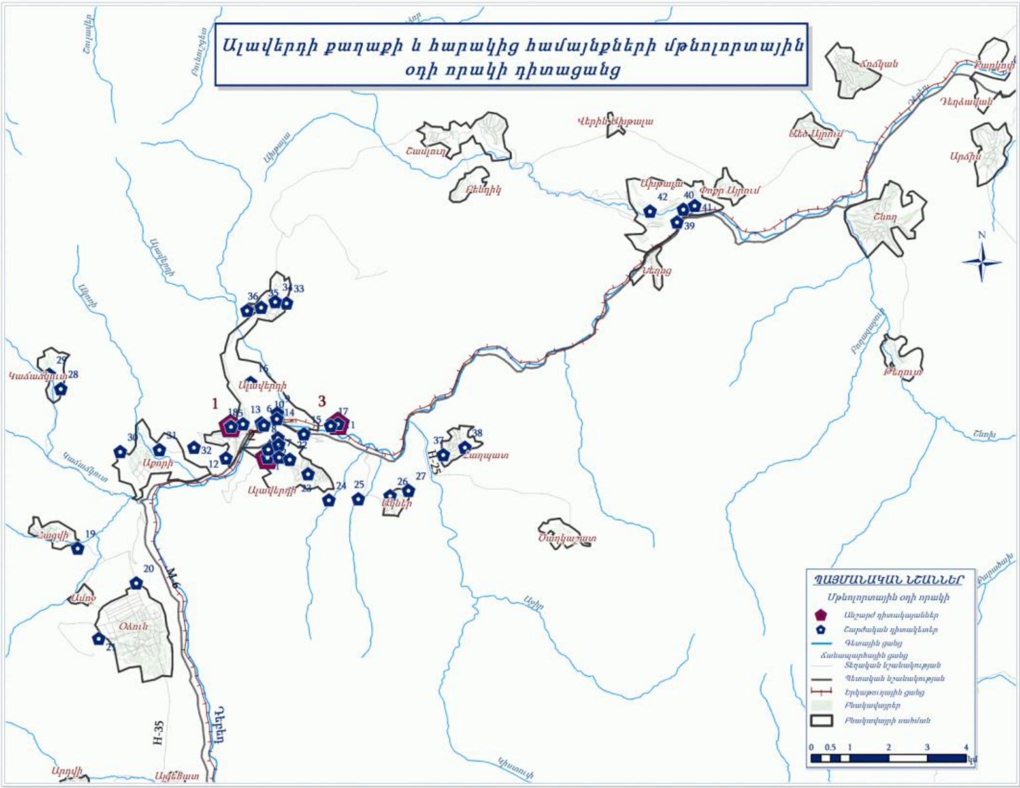
Figure 4: Air quality monitoring network in Alaverdi (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring network in Alaverdi



Source: HMC

Alaverdi N3 station

Source: HMC

Alaverdi N 1 station

Source: HMC

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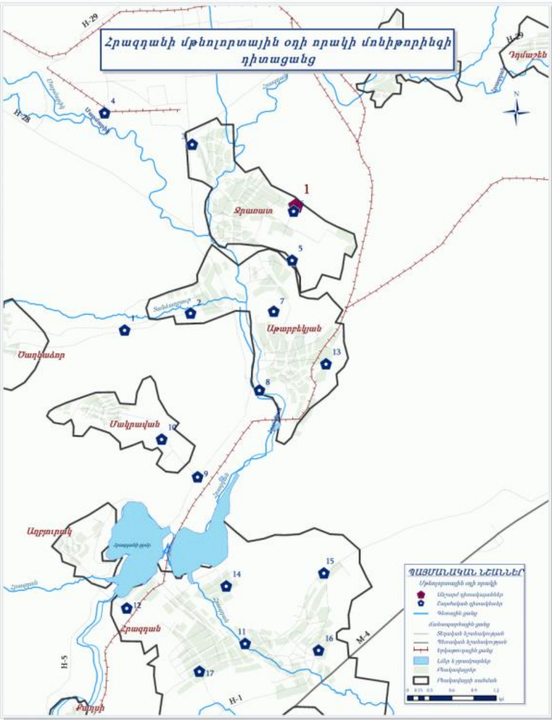
Figure 5: Air quality monitoring network in Hrazdan (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring network in Hrazdan



Source: HMC

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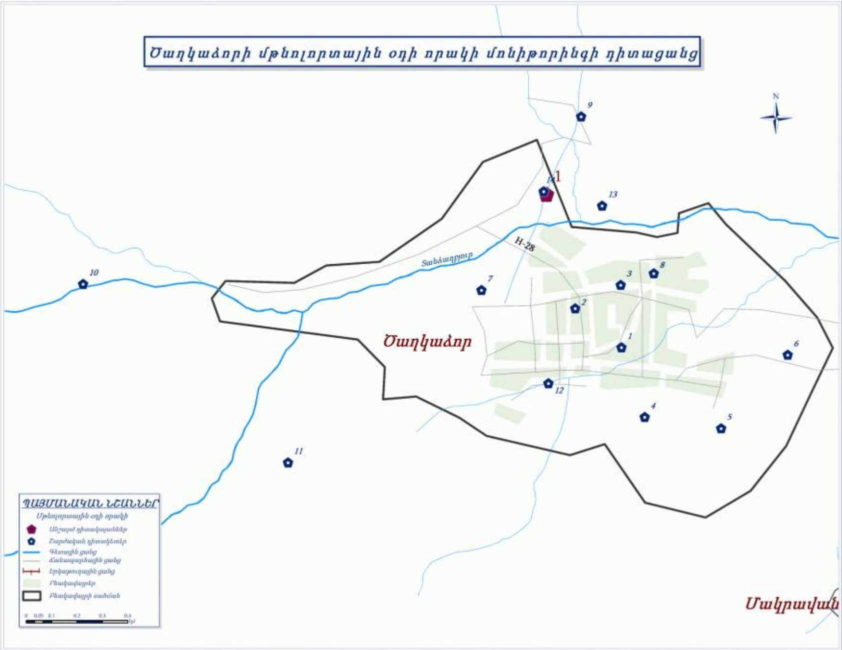
Figure 6: Air quality monitoring network in Tsaghkadzor (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring network in Tsaghkadzor



Source: HMC

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Active sampling monitoring station in Tsaghkadzor

Source: HMC

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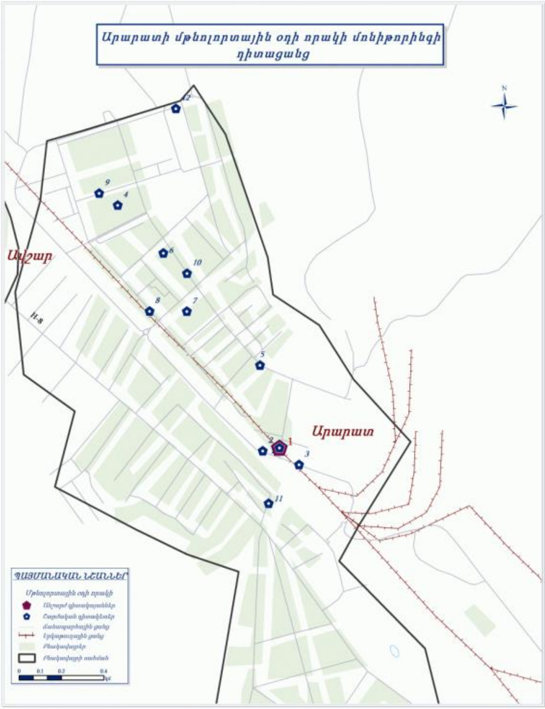
Figure 7: Air quality monitoring network in Ararat (active sampling: red dots, passive sampling: blue dots).

Air quality monitoring network in Ararat



Source: HMC

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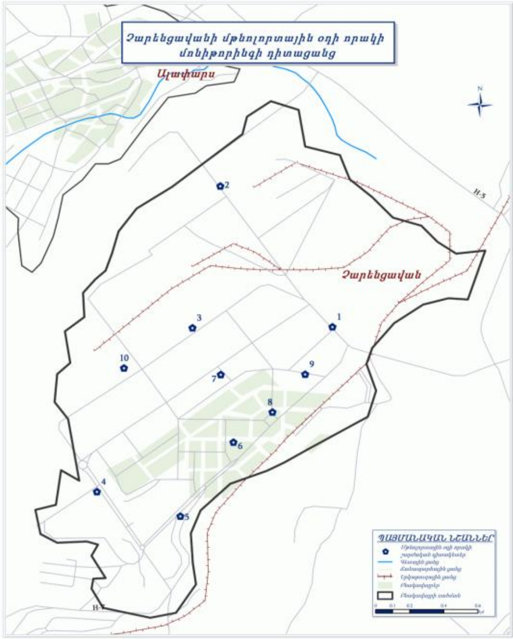
Figure 8: Air quality monitoring network in Charetsavan (passive sampling stations: blue dots).

Air quality monitoring network in Charetsavan



Source: HMC

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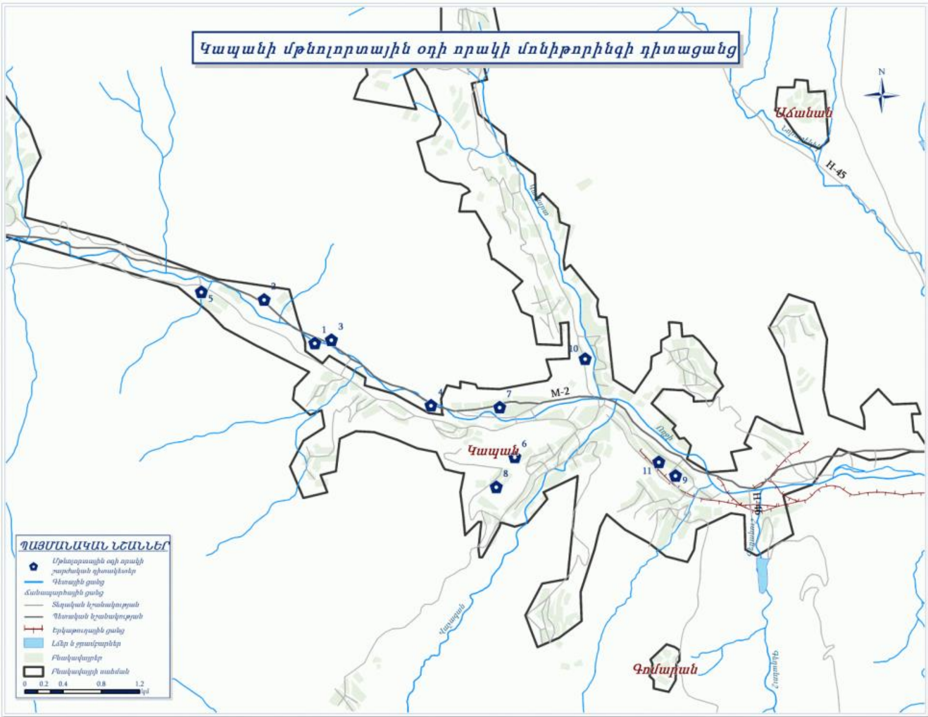
Figure 9: Air quality monitoring network in Kapan (passive sampling stations: blue dots).

Air quality monitoring network in Kapan



Source: HMC

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Figure 10: Air quality monitoring network in Kajaran (passive sampling stations: blue dots).

Air quality monitoring network in Kajaran

Source: HMC

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4.2.2 Description of current manual sampling methods

4.2.2.1 Active sampling

Manual sampling

Monitoring is mainly done by manual sampling based on either wet chemical methods or passive sampling. Within the 15 active sampling stations (Table 2) air quality monitoring is carried out daily throughout the year. The sampling systems consists of a pump, electronic or membrane gas meters and glass tubes impregnated with different reagents (Figure 12). These reagents are available for NO_2, SO_2 and ozone. Similarly, dust (total supended particles, TSP) is sampled with specific filter material (AFA), which is also used for chemical analysis of heavy metals.

Figure 11 shows as an example the sampling system of station N 1 in Yerevan.

Air sampling system in Station N 1 in Yerevan

Source: HMC

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Figure 11: Air sampling system in Station N 1 in Yerevan.

Fritted glass tube with reagents for active sampling

Source: HMC

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Figure 12: Fritted glass tube for active sampling of NO_2, SO_2 or O_3 concentrations in ambient air.

Analysis in laboratory

After sampling, the reagents within the glass tubes is analysed in the chemical laboratory. No recent comparison is available between this manual sampling method and automatic samplers according to European Standards (EN 14212:2012 for SO_2, EN 14211:2012 for NO_2 and NO_x, EN 14625:2012 for ozone).

The following parameters are monitored at these 15 stations (Table 3).

Table 3: Parameters of the active sampling stations (source: HMC).

City	Number of station	Parameters
Yerevan	1	NO_2, SO_2, dust, O_3, heavy metals
	2	NO_2, SO_2, dust, O_3, heavy metals
	7	NO_2, SO_2, dust, O_3, heavy metals
	8	NO_2, SO_2, dust, O_3, heavy metals
	18	NO_2, SO_2, dust, O_3, heavy metals
Ararat	1	Dust, heavy metals
Hrazdan	1	NO_2, SO_2, dust, heavy metals
Tsaghkadzor	1	NO_2, SO_2, dust, heavy metals
Gyumri	1	Dust, heavy metals
Alaverdi	1	NO_2, SO_2, dust, heavy metals
	2	NO_2, SO_2, dust, heavy metals
	3	NO_2, SO_2, dust, heavy metals
Vanadzor	1	NO_2, SO_2, dust, heavy metals
	2	NO_2, SO_2, dust, heavy metals
	3	NO_2, SO_2, dust, heavy metals

Details of the analytical methods are laid down in document provided by HMC to EAA.

4.2.2.2 Passive sampling

Sampling of NO_2 and SO_2

Passive (also called diffusive) sampling is done for NO_2 and SO_2 at 214 locations in the cities listed in Table 2. The samples are changed on a weekly basis and analysed in the chemical laboratory after exposure.

Details of the analytical methods are laid down in document provided by HMC to EAA.

4.2.2.3 Laboratory equipment for chemical analysis

HMC chemical laboratory

The chemical laboratory of HMC was updated in 2019 within the EUWI+ initiative[7]. Table 4 lists the instruments that are currently in use at the HMC chemical laboratory.

[7] https://euwipluseast.eu/en/

Table 4: Current equipment of the HMC chemical laboratory used for ambient air quality sampling (source: HMC).

Instruments	**Operated since**
Inductively coupled plasma mass-spectrometer: ICP-MS, Perkin Elmer ELAN 9000	2003
Ion chromatograph: DIONEX ICS -1000	2007
Ion chromatograph: Metrohm 940 Professional IC Vario	2019
Spectrofotometer: Specord 210 PLUS, Analytik Jena	2020
Spectrofotometer: Specord 205, Analytik Jena	2010
Spectrophotometer Lambda 35 UV/VIS, Perkin Elmer	2008
Multiparameter field Instrument: YSI 556 MPS, YSI Professional Plus, OXY 340i/SET	2019
TOC Analyzer Elementar	2011
Gas Chromatograph-Mass-spectrometer: GC/MS Agilent 7890A/5975C	2010
Gas Chromatograph: Perkin Elmer Clarus 400, GC-FID	2008
Handheld X-ray fluorescence analyzer: XRF- Olympus vanta	2019
Microwave digestion system: Berghof Speedwave MWS-3+	2010
Analytical Balances: Voyager Shimadzu AP224W	2019

The instruments are in principle suitable for the analysis of air quality samples for heavy metals and ions as well. However, the status of the standards and calibration of instruments is not known yet, but will be made available. In addition, it has to be noted, that concentrations can be rather low at some locations, which require high purity materials and adequate sampling handling for trace analysis.

4.2.2.4 Defunct automatic monitors

Automatic samples (defunct)

Around 15 years ago, selected AQ monitoring stations in Yerevan and Alaverdi were equipped with automatic gas analysers for SO_2, NOx and CO (Horiba, Teledyne). Due to a lack in funding for maintenance, calibration, and spare parts, currently only CO is monitored by automatic samplers (Teledyne) at Yerevan station N7. However, the reliability of the measured concentrations has not been validated in recent years.

5 SCENARIOS FOR MODERNIZING THE AIR MONITORING SYSTEM

5.1 Objectives of the air quality monitoring network

Main objectives

An air quality monitoring system serves various purposes at the same time. In general, the main objectives are the following ones:

- Determining compliance status with national or international AQ standards and guidelines;
- Identifying threats to natural ecosystems and environment in general (e.g. climate change, influence on glaciers, ozone layer depletion, acidification, eutrophication);
- Population exposure and health impact assessment;
- Informing the public about air quality and establishing alert systems;
- Identifying relevant pollution sources and source apportionment;
- Providing objective input to environmental management and to transport, land-use and industrial planning;
- Validate air quality models;
- Developing policies, strategies, standards and setting priorities for clean air action plans;
- Developing and validating tools such as models and GIS;
- Quantifying trends to identify future problems or progress in achieving targets.

Specific objectives AQ monitoring in Armenia

Proposed specific objectives for AQ monitoring in Armenia are:

- Monitoring should take place at locations with already existing infrastructure and meteorological observations, in case these locations fulfil the siting criteria of the AAQD. This allows for using synergies in operation and maintenance of these sites.
- Monitored parameters at these sites should consider the local situation and importance of different air pollutants on human health and / or the environment. Therefore, in general the focus should be on $PM_{2.5}$, PM_{10}, NO_2, O_3); in areas influenced by specific industrial facilities SO_2 and heavy metals should be monitored.
- The selection of parameters to be monitored should take into account the need for robust, durable and affordable instruments.
- Next to fixed sites, a mobile station and/or passive sampling campaigns might be foreseen within the long-term extension of the network to allow for a more flexible analysis of the spatial and temporal distribution of air pollutants and specific sources.
- QA/QC procedures should be implemented for operation, maintenance and calibration of the air quality monitoring network as well as for the data

handling. These procedures should follow international standards and guidelines e.g. provided by the European Committee for Standardization (CEN), the International Organization for Standardizations (ISO) or the United States National Institute of Standards and Technology (NIST).

- To ensure representative and traceable data throughout the air quality monitoring network, a national reference laboratory should be established in medium term.
- The collected air quality data should be checked and validated by HMC and fed into a common national air quality database.
- HMC should conduct the monitoring of key meteorological parameters at selected and suitable air quality monitoring sites. This includes QA/QC according to WMO guidelines. The parameters to be monitored include temperature, humidity, precipitation, wind speed, wind direction and global irradiation (at a small number of sites).
- To assess the dispersion conditions, temperature should be monitored at different locations. These should allow the observation of a temperature profile and the identification of temperature inversions.

5.2 Siting of monitoring stations

The location of the future AQ monitoring stations should be in line with the criteria of the AAQD. The AAQD foresees two set of criteria. The first, more general ones are the so-called to **macro-scale siting criteria**. These criteria are applied for setting the type of the monitoring site, i.e. to distinguish between traffic, urban or rural background and industrial sites. The more specific **micro-scale siting criteria** apply for all types of monitoring sites and describe how the immediate vicinity and the air inlet should look like.

Macro-scale siting criteria

Macro-scale siting criteria according to the AAQD provide minimum requirements on the types of locations where measurements to assess air quality have to be performed. It requires that areas are covered where the highest pollution levels are to be expected, as well as areas that are representative for the average exposure of the population. The former are mainly (urban) traffic sites or industrial sites, the latter are urban or sub-urban sites.

Traffic sites, industrial sites

According to the AAQD sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity. This means that a sampling point must be sited in such a way that the air sampled is representative for a street segment no less than 100 m length at **traffic-orientated sites** and at least 250 m × 250 m at **industrial sites**.

Urban background sites

Urban background sites shall be located so that their pollution level is influenced by the integrated contribution from all sources upwind of the station. The pollution level should not be dominated by a single source unless such a situation is typical for a larger urban area. Those sampling points shall, as a general rule, be representative for several square kilometres.

Rural background sites **Rural background sites** shall not be influenced by agglomerations closer than 20 km or industrial sites, motorways or other built-up areas closer than five kilometres.

Industrial sites **Industrial monitoring sites** shall be installed down-wind of the source in the nearest residential area. Where the background concentration is not known, an additional sampling point shall be situated within the main wind direction.

Representativeness In addition, macro-scale siting criteria also provide a basis for establishing the **spatial representativeness** of monitoring sites, so that they are representative of similar locations not only in their immediate vicinity.

Vegetation, ecosystems Sampling points targeted at the **protection of vegetation and natural ecosystems** shall be sited more than 20 km away from agglomerations or more than 5 km away from other built-up areas, industrial installations or motorways or major roads with traffic counts of more than 50 000 vehicles per day, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality in a surrounding area of at least 1 000 km^2. To protect particularly vulnerable areas a sampling point might be sited at a lesser distance or might be representative of air quality in a less extended area.

Micro-scale siting criteria **Micro-scale siting criteria** shall ensure free airflow around the sampling inlet – as a basic requirement for ensuring measurement representative for a defined area – and provide minimum requirements for sampling near major roads. The selection of locations for monitoring sites has to take into account the major emission sources, the main pollutants and the maximum number of stations.

Inlet In detail, the **flow around the inlet** sampling probe shall be unrestricted (in general free in an arc of at least 270° or 180° for sampling points at the building line) without any obstructions affecting the airflow in the vicinity of the inlet (normally some metres away from buildings, balconies, trees and other obstacles and at least 0.5 m from the nearest building in the case of sampling points representing air quality at the building line).

In general, the **inlet sampling point** shall be between 1.5 m (the breathing zone) and 4 m above the ground. Higher siting may also be appropriate if the station is representative of a large area.

The inlet probe shall **not** be positioned in the **immediate vicinity of sources** in order to avoid the direct intake of emissions unmixed with ambient air. In addition, the sampler's exhaust outlet shall be positioned so that recirculation of exhaust air to the sampler inlet is avoided.

Distance to junctions Traffic-orientated sampling probes shall be at least **25 m from the edge of major junctions** and **no more than 10 m from the kerbside**.

Even though it is highly recommended to apply these criteria, they are not mandatory. There might be situations in densely built-up areas where not all criteria can be completely fulfilled. Nevertheless, such a station can and should be used for compliance checking.

Ambient air quality should be assessed in all areas throughout the country that fulfil the criteria for a potential air quality monitoring site.

5.3 Capacity building

Whole chain of AQ monitoring

HMC is on the beginning of implementing an automatic air quality monitoring network. In addition, the implementation of the necessary surrounding infrastructure such as national reference laboratory is pending. Hence, capacity building (laboratory infrastructure, technical manpower, and management system) is required for the whole chain of air quality monitoring. This includes the required capacities for calibration and reference laboratories, for operation and maintenance of the monitoring stations, and data management.

The requirements for these laboratories and these activities are laid down in in the AAQD. These requirements and especially the experience gained over the last twenty years can be taken as a starting point for capacity building in Armenia.

Capacity building and training should be mostly done by practical training, e.g. within a Twinning project and study visits.

5.4 Scenario for parameters and pollutants

Resources and expertise needed

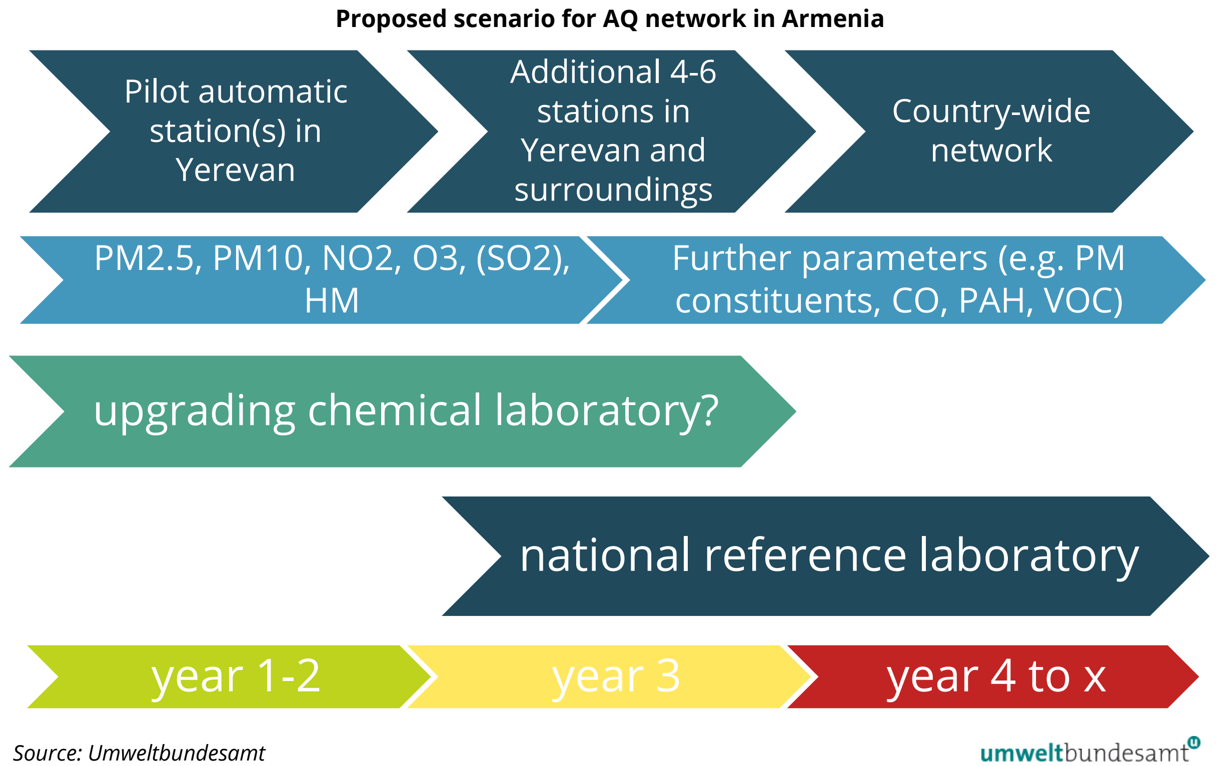
Establishing an automatic ambient air quality network is an enormous task, which requires substantial resources and technical expertise. Therefore, we propose a stepwise approach to allow for the expertise to build up and funding to be secured.

The assessment has shown, that the current air quality monitoring network and much of the supporting infrastructure need fundamental rebuilding and restructuring.

Step-wise approach

A suggestion for steps to be taken to modernize the air quality network and management in Armenia are provided in the following. The practical implementation depends on the decision to go ahead and funding being secured; it should start from the network infrastructure. The following figure provides a schematic overview of the proposed scenario for such a stepwise approach in three phases (Figure 13).

Figure 13: Proposed scenario for establishing an automatic air quality network in Armenia.



Source: Umweltbundesamt

5.4.1 Automatic monitoring stations

Phase I As a first step (phase I), automatic monitoring of selected priority pollutants should start at one or two stations in Yerevan. The main purpose of these two stations is to familiarize and train the staff with the equipment, QA/QC, maintenance etc. As described in section 5.1, the proposed priority pollutants for the first station(s) in Yerevan could be PM_{10}, $PM_{2.5}$, NO_2, NO_x, O_3, if relevant also SO_2. PM monitoring should be undertaken with both a continuous and gravimetric method. This allows on the one hand to inform the public about up-to-date levels, on the other hand the gravimetric method allows for chemical analysis and to prove the equivalence of the continuous method to the reference method (EN 12341:2014). A PM monitor using an optical method should be considered for continuous monitoring. As the mass of the PM material is determined by weighing the filter at specified conditions before and after sampling; daily information of the public is not possible.

Phase II When these stations are successfully operated and funding is secured, further stations should be deployed in Yerevan and the surroundings (phase II). Depending on the air quality situation, further parameters could be monitored at these locations such as PM constituents (SO_4^{2-}, NO_3^-, NH_4^+, Ca^{2+}, K^+, Na^+, Cl^-, Mg^{2+}, elemental carbon (EC), organic carbon (OC)) CO, PAH, HM and VOC.

For Hg and Benzene, we propose using passive samplers for the time being. If necessary, VOC could be monitored via passive sampling close to specific industries.

Phase III In phase III, automatic monitoring stations should be deployed countrywide.

5.4.2 Final number of monitoring sites for the pilot city

Stations per zone and agglomeration In Europe, the number of monitoring sites per zone and agglomeration is laid down in the Ambient Air Quality Directive (AAQD)[8], which can be used a rule of thumb for the final number of stations in the pilot city (Nagl et al. 2019). Annex V A.1 of the AAQD determines the minimum number of fixed monitoring stations for air pollutants[9] (for the protection of human health) per zone with respect to diffuse (i.e. non-industrial) sources, see Table 5 and Table 6 (limited to population numbers occurring in Armenia). The minimum number of monitoring stations per zone depends on the pollution level in relation to the assessment thresholds (specified in Annex II of the AAQD) and the population of the zone.

Table 5: Minimum numbers of sampling points for fixed measurement of gaseous pollutants (source: https://eur-lex.europa.eu/eli/dir/2008/50/oj).

Population of agglomeration or zone (thousands)	If maximum concentrations exceed the upper assessment threshold	If maximum concentrations are between the upper and lower assessment thresholds
0-249	1	1
250-499	2	1
500-749	2	1
750-999	3	1
1000-1499	4	2
1500-1999	5	2

Table 6: Minimum numbers (sum of PM_{10} and $PM_{2,5}$) of sampling points for fixed measurement of gaseous pollutants (source: https://eur-lex.europa.eu/eli/dir/2008/50/oj).

Population of agglomeration or zone (thousands)	If maximum concentrations exceed the upper assessment threshold (sum of PM_{10} and $PM_{2,5}$ sites)	If maximum concentrations are between the upper and lower assessment thresholds (sum of PM_{10} and $PM_{2,5}$ sites)
0-249	2	1

[8] http://data.europa.eu/eli/dir/2008/50/oj, Annex V A. 2 provides criteria for industrial monitoring sites; Annex V B. sets out monitoring requirements for the $PM_{2.5}$ exposure reduction target; Annex V C. sets out criteria for monitoring sites targeting natural ecosystem and vegetation protection. These three types of monitoring stations are not covered in this study.

[9] SO_2, NO_2, NO_x, particulate matter (PM_{10} and $PM_{2.5}$), Pb in PM_{10}, CO, and benzene

250-499	3	2
500-749	3	2
750-999	4	2
1000-1499	5	3
1500-1999	7	3

AQ assessment

The higher the pollution level and population are, the higher the number of monitoring sites required per zone. According to Article 7(3) of the AAQD, the number of monitoring sites may be reduced if air quality assessment is supplemented by modelling or indicative measurements. Where pollution is below the lower assessment threshold, no monitoring sites are required, and the assessment may be based on modelling or objective estimation alone.

Specific requirements call for a fairly equal distribution of traffic-orientated and urban background monitoring sites, i.e. between 0.5 and 2 respectively. These requirements are laid down in footnote 1 to the table in Annex V A 1 of the AAQD.

Further specific requirements provide for a fairly even distribution of PM_{10} and $PM_{2.5}$ monitoring sites, i.e. between 0.5 and 2 respectively. These are laid down in footnote 2 to the table in Annex V A 1.

Annex IX sets out the minimum numbers for ozone monitoring sites per zone

The AAQD is less specific for **point sources**. It requires "*For the assessment of pollution in the vicinity of point sources, the number of sampling points for fixed measurement shall be calculated taking into account emission densities, the likely distribution patterns of ambient-air pollution and the potential exposure of the population*."

5.4.3 Instrumentation and proposed standard methods

Reference methods

Analytical principles and reference measurement methods for criteria pollutants commonly used are shown in Table 7. The proposed standard methods will follow these principles.

Table 7: Measuring principles of the reference methods.

Criteria Pollutants	Measuring principle of reference methods
Particulate matter (PM)	Gravimetry
Carbon monoxide (CO)	Non-dispersive infrared spectroscopy
Nitrogen oxides (NO_x)	Chemiluminescence
Ozone (O_3)	Ultraviolet photometry
Sulfur dioxide (SO_2)	Ultraviolet fluorescence

Proposed methods

Proposed standard methods for monitoring of proposed air quality parameters:

- Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence (Ref. EN 14211:2012 or equivalent)
- Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence (Ref. EN 14212:2012 or equivalent)
- Standard method for the measurement of the concentration of ozone by ultraviolet photometry (Ref. EN 14625:2012 or equivalent)
- Standard method for the measurement of the concentration of carbon monoxide by nondispersive infrared spectroscopy (Ref. EN 14626:2012 or equivalent)
- Standard method for the automatic measurement systems for the measurement of the concentration of PM_{10} & $PM_{2.5}$ (Ref. EN 16450:2017 or equivalent)
- Standard gravimetric measurement method for the determination of PM_{10} & $PM_{2.5}$ mass concentration (Ref. EN 12341:2014 or equivalent)
- Standard method for the measurement of benzene concentration by diffusive sampling technique followed by solvent desorption and gas chromatography (Ref. EN 14662-5:2005 or equivalent)
- Standard method for the measurement of the concentration of benzo[a]pyrene (PAH) in ambient air (Ref. EN 15549:2008 or equivalent).
- Standard method for the measurement of heavy metals (Pb, Cd, As, Ni) in PM_{10} (Ref. EN 14902:2005 or equivalent).
- Standard method for measurement of NO_3^-, SO_4^{2-}, Cl^-, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} in $PM_{2.5}$ (Ref. EN 16913:2017).
- Standard method for the measurement of elemental carbon (EC) and organic carbon (OC) collected on filters (Ref. EN 16909:2017).

Lists of type-tested and certified equipment for ambient air quality monitoring which fulfils the requirements of the above proposed European standards have been published e.g. by the European Commission[10] and by authorities in Germany[11] and in the United Kingdom[12].

Recommendations WMO for meteorological parameters

For **meteorological parameters** (temperature, humidity, wind speed and wind direction, global irradiation and precipitation) all monitoring should be done with the help of automatic sensors. We propose to follow the recommendations for instrumentation and quality assurance according to WMO[13].

[10] https://db-airmontech.jrc.ec.europa.eu/index.aspx

[11] https://www.qal1.de/en/index.htm

[12] https://www.gov.uk/government/publications/mcerts-performance-standard-for-continuous-ambient-air-quality-monitoring-systems

[13] https://community.wmo.int/activity-areas/imop/wmo-no_8

Standard operation procedures

Standard operation procedures (SOP) based on the listed standards should be prepared with the involvement of national and international consultants who are aware about the HMC air quality monitoring system after the finalization of air quality monitoring parameters and equipment selection. This is required to ensure that only authorised and approved modifications are made to these documents and to maintain a complete version history of this protocol and ensure that all associated data can be synthesized, analysed and reported.

In addition, we recommend preparing standard operating procedures, which cover the following issues:

- Standard operating procedure for data acquisition, processing and management;
- Standard operating procedure for equipment and service procurement (BID document);
- Standard operating procedure for training and capacity building of professionals and officials;
- Standard operating procedure for occupational health and safety.

5.4.4 Quality assurance, quality control

Air quality management system

The QA / QC is a prerequisite to deliver traceable and accurate data linked to primary standards. The QA / QC scheme is necessary to ensure the success of the complete program. The design of an effective and targeted QA / QC program is the first step in the process of air quality management system. The program needs to be fully documented, and compliance with its objectives, procedures and requirements actively monitored. The monitoring programs evolve over time as objectives, legislation, resources or air pollution problems change. The quality assurance programs are required to be regularly reviewed to ensure that they remain properly targeted and fit for purpose. The overall objectives for QA / QC air monitoring shall cover following issues:

- Accurate and precise measurements, which are traceable to primary standards;
- Representative data on ambient exposure conditions;
- Traceability and consistency in measurement over time;
- High data capture and evenly distributed data over time;
- Resource optimization.

Major components of quality assurance

All pre-assessment phases of monitoring, including determining monitoring site locations and data quality objectives, system design, site selection, equipment selection, equipment evaluation and operator training activities are quality assurance activities. Quality control functions affect directly measurement - related activities such as site operation, calibration, data management, field audits and training. The major components of quality assurance for air monitoring include,

- Definition of monitoring and data quality objectives;

- Network design, management and training systems;
- Site selection and establishment;
- Equipment evaluation and selection;
- Routine site operations.

Similarly, major components of quality controls for air monitoring include:

- Establishment of calibration / traceability chain;
- Network audits and inter-calibrations;
- System maintenance and support;
- Data validation, incl. outlier checks, and data correction after calibration.

As described above, in order to produce quality assured data that are correct, meaningful and useful (and traceable to primary standards in the optimum case), the measurement techniques utilised and data handling must have a sound scientific basis. The data must be both accurate and precise.

Requirements for data quality

The European AAQD defines Data Quality Objectives (DQO) which specify uncertainty, minimum data capture, minimum time coverage (where appropriate) for fixed and indicative measurements, for each pollutant covered by the Directive. The reference methods of measurement for the various pollutants are defined as the relevant CEN standard methods. These standard methods provide details of the reference method of measurement for each pollutant, specific analyser tests to be performed and requirements for the on-going regular QA/QC activities for the analysers and associated systems for sampling, data collection and data transmission. In addition, these standards provide a methodology for uncertainty evaluation to enable the overall measurement uncertainty of the method to be directly compared with the specified DQOs. The QA/QC measures as defined through International Standardization Organisation (ISO) will also be incorporated.

These definitions are interpreted by the European network of national air quality reference laboratories (AQUILA), in relation to the operations of air quality networks operations, as meaning: Quality assurance refers to the overall management of the process involved in obtaining the data, whereas quality control refers to the activities undertaken to check and optimise data accuracy and precision after collection. Hence, quality assurance relates to the measurement process, whilst quality control is concerned primarily with its outputs. For ambient air quality monitoring networks, quality assurance activities should include (AQUILA 2009)[14]:

- Network design;
- Station siting (macro and micro siting criteria);
- Instrument selection;

[14] http://ec.europa.eu/environment/air/quality/legislation/pdf/aquila.pdf

- Instrument operations;
- Instrument maintenance;
- Operator training;
- Instrument calibration;
- Specifications for on-going inspections and maintenance of the systems/stations etc.;
- Site, analyser, and site calibration standard audit;
- Data handling, validation and management.

Quality control activities should include:

- On-site instrument checks;
- Data checking, validation and correction (if necessary);
- Quality review and feedback of this into the results;
- Participation in relevant comparison exercises.

5.4.5 Operation and maintenance

Highest possible quality

The operator of the air quality monitoring site is responsible to ensure that the data output is uninterrupted and of the highest possible quality. This includes the following key activities:

- Routine operation and maintenance procedures are carried out in conformance with the proposed standards and SOP (see section 5.4.3).
- Routine calibration procedures are carried out in conformance with the proposed standards and SOP.
- Problems, faults, malfunctions etc. at the monitoring site are identified, reported and solved.
- Repairs of the equipment are undertaken as described by the manufacturer or in coordination with the manufacturer.
- The required adequate consumables and spare parts for the maintenance of the equipment are available.
- The air quality monitoring site including the site infrastructure and its surroundings are kept in a good state and tidy.
- Information on local activities that may influence the air quality at the station are provided to HMC.

It is recommended that routine site visits should take place every 2 weeks if possible. Additional non-routine visits for troubleshooting in case of analyser malfunctions or other problems may be necessary.

Routine service

Routine service and maintenance of the instruments at the monitoring site should be carried out in accordance with the recommendations of the manufacturer. The required frequency of maintenance as defined in the proposed standard methods is shown in Table 8. Typical procedures carried out during routine service and maintenance should include:

- Replacement of all consumable components (e.g. particulate filter, O-rings, scrubber materials etc.);
- Dismantling and cleaning of the sampling manifold;
- Servicing of the equipment (analysers, zero air generator, auto-calibration facilities, data loggers) according to the manufacturers manual;
- Servicing of the air conditioning units according to the manufacturers recommendation.

Table 8: Required frequency of maintenance.

Maintenance	**Frequency**	**Action criteria**
Change of particle filters of the sampling system at the sampling inlet and/or at the analyser inlet	The particle filter shall be changed periodically depending on the dust loading at the sampling site but at least every three months. Overloading of the particle filter may change the concentration of pollutants. The filter housing shall be cleaned every six months.	
Changing of consumables	As required by manufacturer	As required
Preventive/routine maintenance of components of the analyser	As required by manufacturer	As required
Testing sample manifold: Influence of pressure drop induced by the manifold pump Sample collection efficiency	At least every three years	Influence ≥ 1,0 % of measured value. Influence ≥ 2,0 % of measured value
Testing sampling lines	At least every six months	≥ 2,0 % sample loss

The site visit also provides the opportunity to check, if applicable repair and/or replace many items of the site infrastructure.

All site visits must be fully documented and describe in detail any adjustments modification or repairs undertaken.

5.4.6 Checks and calibration procedures

The frequency of checks and calibrations according to the proposed standard methods are summarised in Table 9. In addition, criteria for readjustment, calibration or maintenance of an analyser are given.

Table 9: Required frequency of checks and calibration

Checks, calibration	Frequency	Action criteria
Zero and span check	At least every two weeks, strongly recommended every 23 or 25 h	Zero: ≤ -4,0 or ≥ 4,0 nmol/mol Span: ≥ 5,0 % of initial span value
Calibration of the analyser	At least every three months and after repair	Zero or span drift beyond the tolerances set by the user
Repeatability at zero and span of the analyser	In combination with calibration, using the data from the calibration	Repeatability standard deviation: at zero: ≥ 1,0 nmol/mol at span: ≥ 1,5 % of span concentration
Verification of gases used for zero and span checks	At least every six months	Zero: ≥ detection limit Span: ≥ 5,0 % of previous verification
Lack of fit check	Within one year after initial installation and after repair	Lack of fit > 4,0 % of the measured value Lack of fit > 5,0 nmol/mol at zero

5.4.6.1 Zero and span checks

Daily checks

Daily automatic zero and span analyser checks provide valuable information on the routine performance of analysers and any long term response drifts. Zero and span checks are performed by introducing zero air and a span gas concentration through the system but not making any actual adjustments. The checks are controlled automatically by the data logger or analyser software, and do not normally need any adjustment. Recording the instrument response at zero and span concentrations provides a way to determine instrument reliability and drift over time. It is recommended that these checks usually should take place every 23 or 25 h.

Zero and span gas can be supplied by gas cylinder, or generated by an external calibrator unit or internally in the analyser. The concentration of the span gas shall be around 70 % to 80 % of the maximum of the certification range or the user-defined range. The stability of the gases used for span and zero checks shall be verified at least every six months with use of reference gases traceable to (inter)nationally accepted standards.

Zero checks on Particulate Analysers

Because it is difficult to generate an air stream containing a specific concentration of particulate matter of the relevant size fraction (PM_{10} or $PM_{2.5}$), it is not possible to provide a system to carry out daily automatic calibrations on the particulate analyser.

Zero check However, it is possible to carry out a zero check, which involves fitting a filter on the inlet in place of the PM head, so that the instrument samples particulate-free air over this period.

5.4.6.2 Lack of fit check

The lack of fit of the analyser shall be tested using at minimum the following concentrations: 0 %, 60 %, 20 %, and 95 % of the maximum of the certification range of sulphur dioxide or the user-defined range. At each concentration (including zero) at least two individual readings shall be performed. After each change in concentration, at least four response times shall be taken into account before the next measurement is performed.

Calibration of analyser

The calibration of monitoring instruments for gaseous contaminants requires a calibration gas, a zero air supply and some means of delivering a known calibration gas concentration to the instrument being calibrated. In addition, calibration of flow, temperature and pressure sensors is necessary. Only calibration gases that are traceable to standard reference materials should be used. It is crucial that the zero air supply is as free of analytes (and interfering species) as possible and that the supply of span gas is known accurately and delivered with precision. Examples for the specifications for the purity of zero gas and span gas for the measurement of nitrogen monoxide and nitrogen dioxide are given in Table 10 and Table 11.

Table 10: Specification for purity of zero gas for measurement of NO and NO_2 (Source: EN 14211:2012).

Pollutant	Concentration
Carbon monoxide (CO)	≤ 4 µmol/mol
Ozone (O_3)	≤ 2 nmol/mol
Ammonia (NH_3)	≤ 1 nmol/mol
Water	≤ 150 µmol/mol
Nitrogen monoxide (NO)	≤ 1 nmol/mol
Nitrogen dioxide (NO_2)	≤ 1 nmol/mol

Table 11: Specification for purity of span gas for measurement of NO and NO_2 (Source: EN 14211:2012).

Pollutant	Concentration for interferents testing	Concentration for other tests
Carbon monoxide (CO)	≤ 4 µmol/mol	≤ 400 µmol/mol
Ozone (O_3)	≤ 2 nmol/mol	≤ 2 nmol/mol
Ammonia (NH_3)	≤ 1 nmol/mol	≤ 10 nmol/mol
Water	≤ 150 µmol/mol	≤150 µmol/mol
Nitrogen monoxide (NO)	≤ 1 nmol/mol	≤ 1 nmol/mol
Nitrogen dioxide (NO_2)	≤ 1 nmol/mol	≤ 1 nmol/mol

Calibration every 3 months

It is recommended that calibration of the analysers at the monitoring site shall be performed at least every three months and after repair at a concentration of 70 % to 80 % of the certification range, to determine analyser response and drift. According to the European standards for gaseous components, the three-monthly interval may be extended to six months when analyser stability can be demonstrated. A measure for this may be the results of zero and span checks over a three-month period being ≤ 2 %.

Calibration of automatic particulate analysers

Calibration every year

We recommend that the calibration of automatic particulate monitors should be carried out at least every year. As the procedures for calibration may vary considerably depending upon the type of monitor and the principle of measurement, and it will be necessary to refer to the manufacturer's recommended procedures.

The frequency of checks and calibrations according to the proposed standard method for automatic measurement of PM is summarised in Table 12. In addition, criteria for readjustment, calibration or maintenance of an analyser are given.

Table 12: Required frequency of checks and calibration for automatic particle monitors (Source: EN 16450:2017).

Checks, calibration	Frequency	Action criteria
Checks of status values of operational parameters	Daily	
Checks of sensors for temperature, pressure and/or humidity	Every 3 months	± 2 °C ± 1 kPa ± 5 % RH
Calibration of sensors for temperature, pressure and/or humidity	Every year	± 1.5 °C ± 0.5 kPa

Checks, calibration	Frequency	Action criteria
		± 3 % RH
Check of the AMS flow rate(s)	Every 3 months	± 5 %
Calibration of the AMS flow rate(s)	Every year	± 1 %
Leak check of the sampling system	Every year	± 2 %
Zero check of the AMS reading	Every year	± 3 µg/m³
Check of the AMS mass measuring system	As recommended by the manufacturer and after repair, at least every year	± 3 %
Regular maintenance of components of the AMS	As required by the manufacturer	

5.4.7 Further modernization of the chemical laboratory

The chemical laboratory has been upgraded within the EUWI+ project.

PM filters, benzene

As stated above, the laboratory analysis of PM filters and benzene are proposed under phase II. This includes:

- Preparation, conditioning and weighing of PM filters for gravimetric measurements;
- Main PM constituents (ammonium, sulphate, nitrate, carbonaceous components, ...);
- PAH including Benzo(a)pyrene;
- Heavy metals including lead;
- Benzene.

Accredited laboratory

It is recommended that these analyses will be carried out by an accredited laboratory according to ISO/IEC 17025 or at least by a laboratory with an approved quality assurance programme.

For conditioning and weighing of PM filters, a climate-controlled facility like either a suitable room or cabinet has to be used. The requirements on such a weighing facility are summarized in Table 13.

Table 13: Requirements on weighing facilities and procedures for proposed standard method EN 12341:2014 for gravimetric measurement of PM_{10} and/or $PM_{2.5}$.

Parameter	Requirement
weighing room conditions	Temperature: 19°C – 21°C measured as hourly mean value,

	Relative humidity: 45 % RH – 50 % RH measured as hourly mean value
monitoring of conditions	monitoring and documentation of at minimum hourly averages, sensor check every 6 months, calibration at least once a year
balance	resolution: < 10 µg, calibration at least once a year
filter identification	identification required
unloaded filter	conditioning > 48 h before weighing, weighing twice with an interval of at least 12 h
loaded filter	conditioning > 48 h before weighing, weighing twice with an interval of at least 24 h

Chemical analysis

For the chemical analysis of the PM filters, the required resources and methods for sample treatment and analysis are provided in Table 14.

Table 14: Required sample treatment and analysis method for proposed standard methods for chemical analysis of air samples

Standard method EN 16913:2017 (range of anions and cations in $PM_{2.5}$)	
Sample treatment	Extraction with ultrapure water
Analysis	Ion chromatography (IC) Inductively coupled plasma optical emission spectrometry (ICP-OES) for cations, excluding ammonium
Standard method EN 15549:2008 (B(a)P in PM_{10})	
Sample treatment	Extraction with organic solvent (soxhlet extraction, microwave extraction, extraction under reflux, ultrasonic extraction or accelerated solvent extraction)
Analysis	Gas chromatography - mass spectrometry (GC-MS) or High performance liquid chromatography – fluorescence detection (HPLC-FLD)
Standard method EN 14902:2005 (As, Cd, Pb, Ni in PM_{10})	
Sample treatment	Closed vessel microwave digestion using nitric acid and hydrogen peroxide
Analysis	Graphite furnace-atomic absorption spectrometer (GF-AAS) or Inductively coupled plasma – mass spectrometer (ICP-MS)
Standard method EN 14662-5:2005 (Benzene in ambient air)	

Sample treatment	Solvent desorption with carbon disul-phide
Analysis	Gas chromatography (GC)

5.4.8 National Reference Laboratory

Reference laboratory at a later stage

The quality of air pollution data is crucially important for reliable analysis of pollution levels, health impacts and air quality management. The traceability of air quality measurements requires a calibration laboratory within each monitoring network in the short term and a national reference laboratory (NRL) in the long term. Establishing a national reference laboratory is a demanding task. Therefore, such a laboratory should be implemented only after experience has been gained from operating and maintaining automatic instruments, getting in touch with and learning from other national reference laboratories, having established a QA/QC system. This designated NRL should be responsible for the following:

- Approval of measuring systems (methods, equipment, networks and laboratories),
- Ensuring the accuracy of measurements,
- Analysis of assessment methods,
- Coordination and organisation of national quality assurance programmes.

AQUILA

AQUILA, the European network of national air quality reference laboratories describes the roles and tasks[15] of an NRL, which include:

- Implementation of a quality system in the laboratory,
- Approving measurement systems (instruments, laboratories, networks),
- Ensuring the traceability of the measurements at national level, by providing/certifying reference materials to networks,
- Organising intercomparisons/round robin tests at national level,
- Participating in QA/QC programmes and supporting the organisation of such programmes,
- Exchanging information through the organisation of training sessions, workshops, conferences and guidance documents.

Traceability requires an unbroken chain of measurements all with stated uncertainties - from a primary international or national standard to the final measurement result. Each step in the measurement chain results in a slight increase in overall uncertainty.

[15] https://ec.europa.eu/jrc/en/aquila/national-reference-laboratories-role-and-tasks, AQUILA 2009.

As it can be seen from the list of members[16] of the European network of national reference laboratories (AQUILA) these reference laboratories are usually operated by a national (environment) agency.

5.4.9 Technical recommendations for needed investments

5.4.9.1 Equipment Housing

Monitoring stations can be installed in stand-alone, self-contained cabinets or they can be sited in pre-existing buildings (note: as stated above, the current housings have to be replaced). Where a number of air quality monitoring analysers are to be housed in stand-alone, self-contained cabinets, the housing should be of adequate size (typically 3.0 m × 2.0 m × 2.5 m high) to accommodate the instrumentation.

Each housing shall be typically supplied with the following installations:

- Electrical systems and lightning with overvoltage protection;
- Air conditioning and ventilation in case of AC-failures;
- Gas cylinder storage (rack);
- Fixed mounting racks for monitors;
- Uninterruptible power supply (UPS) battery backup system;
- Telephone lines / mobile communication lines (e.g. GPRS).

Air conditioning

Stable temperature

Freestanding monitoring station housings should be fully air conditioned in order to maintain a stable operating temperature of approximately 20-25°C within the enclosure. Typically, analysers can operate within a temperature range 15-35°C; however, in order to ensure a stable instrument response it is important to reduce the operating temperature variation to a minimum. It is also important that instrument calibrations are performed within a known, consistent and stable temperature range. Because a constant temperature must be maintained within the enclosure, doors must, whenever possible, be kept closed.

The air conditioning unit must be able to maintain the internal temperature at 20-30°C with typically a 3 kW equipment load and an ambient temperature of up to 35°C.

The heat exchanger must be positioned where it cannot affect the ambient air being drawn in through the inlets.

[16] https://ec.europa.eu/jrc/en/aquila/members

5.4.9.2 Sampling System

Manifold system

The gas sampling manifold system has to fulfil the following requirements:

- Sampling point (inlet) has to extend vertically through the roof of the housing to a height of 1.5 m above the roof, thereby giving 360° unrestricted flow;
- Inlet protection against rainwater, insects or large particulate matter;
- Prevention of condense water inside the sampling inlet. Condensation may occur in the case of high ambient temperature and/or humidity. The sample line may be moderately heated to avoid condensation.
- Good isolation of the breakthrough to the roof with fittings which are easy to change;
- Sampling line shall be as short as practical to minimise the residence time in the sampling system from the sampling inlet to the inlet of the analyser < 5 sec.;
- Sample inlet and sampling line shall be constructed of corrosion-proof and chemical inert material at least concerning all of the air pollutants measured, such materials are polytetrafluoroethylene (PTFE), borosilicate glass or stainless steel;
- Easy access for cleaning and maintenance, possibility for manual cleaning of the sampling line, possibility to take apart and maintenance half yearly;
- Connection (tube) from the manifold to the monitors max. 2 m and consisting of PTFE or another chemical inert material;
- Connection for at least 10 monitors, size of outlets has to fit monitor inlets;
- Control and regulation of sample flow rate including installation of a flow alarm system.

Particulate filter

A particulate filter shall be placed in the sample line before the inlet of the analyser to retain all particles, which are likely to alter the performance of the analyser.

- Filter material: PTFE;
- Material of the filter housing: chemically inert (e.g. PTFE, borosilicate glass or stainless steel);
- Pore size of the filter: 5 µm.

Sampling pump

A sampling pump for the manifold for sampling ambient air through the manifold is necessary. It is recommended that:

- the inlet of the pump or fan is located at the end of the sampling manifold,
- the pump or fan ensuring a volume flow of 3-6 m^3/h,
- a flow alarm system is installed,
- and that the influence of the pressure drop induced by the manifold sampling pump on the measured concentration is below 1 %.

Sampling inlet for particulate analyser

PM inlet

A separate sample port in the roof of the housing is used to feed a sampling tube from the automatic PM-analyser to the PM_{10} or $PM_{2.5}$ inlet mounted externally on the roof.

5.4.9.3 Calibration facilities

The proposed checks and calibration procedures require the following equipment at the monitoring site:

- Zero air generator;
- Span gas generator (dilution of gas mixtures or permeation tubes for SO_2, NO, CO and generation of ozone by UV-radiation);
- Transfer standard calibration systems.

5.4.10 IT infrastructure

Aggregation period?

From the IT point of view, it is a must to know the aggregation periods of the initial data, before creating any concept about an information system.

- In case data is obtained around "3 times a day" it's possible/reasonable to use Excel or other files to transfer data.
- In case data is obtained by automatic analysers every hour it would be necessary to have an on-line connection and therefore different technical equipment, etc.
- In the future, automatic monitoring stations will be established, according to this concept. This includes automatic data collection.
- Nevertheless, manual data collection will be in use for quite some time; passive samplers and other manual methods such as deposition will be in use for the time being
- Therefore, both data transfer methods, e.g. transfer of Excel files via internet and online, continuous data transfer will be needed for automatic methods.
- Further exchange at operational level regarding IT personnel and technical capacities will be needed.
- Developing a simple application and a database for the air quality data is an option for the current situation. It should collect all the daily measurements results and calculated data. The application should allow:
  - Automated data input - initial measurement results, importing Excel files for the all previously accumulated data and MS Access files for new data;
  - The structure of the input file should be similar to the structure of the current data structure, which is currently populated on a daily basis.

Nevertheless, international standards and data formats, which are e.g. described in the Commission Implementing Decision 2011/850/EU[17] and its guidance documents[18], should be taken into account as well. By that, laborious restructuring or reformatting of data is avoided.

  - Access to all the entered data for update, corrections, etc., in sophisticated way, by observation place, by city, by date, etc.;
  - Creating output files, monthly and other reports;
  - Creating backup files;
  - Other.
- Such an application is a first step towards a new automatic information process from the monitoring station to the end user.
- Using an application and a database in future should not prevent or exclude performing current processes and registering data on hardcopies / paper; at least until it is approved and the application and database are properly functioning.
- The database and application could be developed and implemented in a combination of MS Office Standard tools and “open source” software, which allows using software without purchasing additional licenses and charges.
- A very good option is using MS Access and Visual Basic/SQL as platforms for developing the application and for creating the database. It will be reasonable to install the application and the database on a standalone computer. These platforms allow achieving excellent results in short time and functioning of a system with minimum equipment and finance support. The data could be transferred in the future to any other database, build on different platform if/when this will be needed.
- However, the most appropriate option should be discussed in detail with the local IT experts.

5.5 Cost estimate for a pilot station, including QA/QC

5.5.1 Pilot station

Parameters for phase I to III

In the table below a cost estimate for a pilot station is provided, which would include all parameters for phase I to III, i.e. including Black Carbon, CO etc. The numbers given below are based on costs for typical equipment in Europe, without taxes, custom fees, additional transportation costs etc. that might apply to Armenia.

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2011.335.01.0086.01.ENG

[18] https://www.eionet.europa.eu/aqportal/doc/IPR%20guidance_2.0.1_final.pdf

Line Item N°	Description	Quantity and physical unit	Unit price (EUR)	Total cost estimate (EUR)
1	Equipment housing and installations including: cabinet, electrical installations and light, UPS system, air conditioning and ventilation, gas cylinder storage, installation of analysers and devices, telephone lines / mobile communication lines, container and device status sensors.	1 unit	€ 40,000	€ 40,000
2	Sampling system: Gas sampling manifold system with particulate filter, sampling pump and sampling inlet for particulate analyser	1 unit	Included in costs for equipment housing and installations (item N° 1)	Included in costs for equipment housing and installations (item N° 1)
3	Analyser equipment:			
	3.1 Automatic analyser for PM_{10} and $PM_{2.5}$ The costs depends on the type of analyser (e.g. oscillating microbalances, ß-ray attenuation, or in-situ optical methods). Note: phase 1 parameter	1 unit	€ 20,000 – € 35,000	€ 20,000 - € 35,000
	3.2 Automatic analyser for $NO/NO_2/NO_x$ Note: phase 1 parameter	1 unit	€ 10,000	€ 10,000
	3.3 Automatic analyser for O_3 Note: phase 1 parameter	1 unit	€ 10,000	€ 10,000
	3.4 Automatic analyser for SO_2	1 unit	€ 10,000	€ 10,000

Line Item N°	Description	Quantity and physical unit	Unit price (EUR)	Total cost estimate (EUR)
	Note: phase 2 parameter			
	3.5 Automatic analyser for CO Note: phase 2 parameter	1 unit	€ 10,000	€ 10,000
	3.6 Automatic analyser for black carbon Note: Note: phase 3 parameter	1 unit	€ 30,000	€ 30,000
	3.7 Sequential sampler for gravimetric measurement of PM_{10} Note: phase 1 parameter	1 unit	€ 25,000	€ 25,000
4	Equipment for QA/QC: 4.1 Zero air generator 4.2 Multi-gas calibration unit for calibration of $NO/NO_2/NOx$, O_3, SO_2 and CO 4.3 QA/QC for automatic analyser for particulate matter (external flow meter, mass foil calibration set)	1 unit	€ 40,000	€ 40,000
5	Meteorological equipment: 5.1 Temperature sensor 5.2 Humidity sensor 5.3 Wind speed and wind direction sensor 5.4 Global irradiation sensor 5.5 Atmospheric pressure sensor 5.6 Automatic precipitation gauge	1 unit	€ 10,000	€ 10,000

Line Item N°	Description	Quantity and physical unit	Unit price (EUR)	Total cost estimate (EUR)
	Note: Meteorological equipment is not needed if there will be an AWS on the monitoring site or nearby.			
6	Data management system: data logger system, PC/notebook for monitoring site and data management system at central unit	1 unit	€ 30,000	€ 30,000
7	Consumables and spare parts for the first 24 months from commissioning	complete set	€ 6,000	€ 6,000
8	Documentation and Training: Three sets of hard copies and an electronic copy of technical documentation and operation manuals in English. Training of technical staff on the operation, maintenance and calibration of the pilot air quality monitoring station (at least 2 people) and the operation of the data management system (at least 2 people).	lump sum	€ 1,000 per day	€ 1,000 per day
Total cost estimate excluding VAT				€ 250,000 - € 300,000

5.5.2 Calibration laboratory

No cost estimate is readily available.

5.5.3 Transfer calibration, transfer standards

No cost estimate is readily available

5.5.4 Weighing room

For gravimetric analysis of PM filters, the laboratory needs an air-conditioned weighing room, which has to be kept within a specified temperature and relative humidity range. A rough estimate of costs are:

- Micro balance: 20.000 €.
- Air-conditioned room: 30.000 €.

5.5.5 IT costs

A cost estimate will be provided after further discussion with local IT experts

6 IMPLEMENTATION OF THE PILOT STATIONS

6.1 Siting of the pilot stations

The European Environment Agency published a guidance on preliminary assessment under European Union air quality directives (EEA 1998).

The goal of such an assessment is to get an overview on the distribution of pollutant concentrations and areas with possible exceedances of thresholds. This information can be used in combination with the general criteria for siting of monitoring stations (see section 5.2) to decide on possible locations for pilot stations in Yerevan.

Based on the guidance the following sources of information are proposed, which were discussed during the mission from 4 to 8 July 2022 as well:

- Assessment of existing air quality stations in Yerevan;
- Results of ongoing passive sampling of NO_2 and SO_2;
- Topography, building densities;
- Meteorology;
- Traffic data;
- Emission data.

The availability and usability of these data and information is summarised in the following sections.

6.1.1 Existing air quality monitoring stations

During the July 2022 mission, the experts visited together with HMC 4 existing air quality stations in Yerevan (stations #1, #7, #8, #18). The experts concluded that none of these station fulfil completely the criteria for either a hotspot (traffic) or an urban background station (see section 5.2). It was therefore proposed that new locations should be found for the pilot station(s), which fulfil the criteria and therefore provide more representative levels for AQ.

6.1.2 Results of passive sampling

The following figures show the location of the passive samplers in Yerevan as well as the 5 highest concentrations in 2021 and that of the four stations visited during the mission in July 2022. The highest concentrations were monitored at passive sampling site #3, followed by sites #21 and #22, which coincide with monitoring stations #18 and #7, respectively.

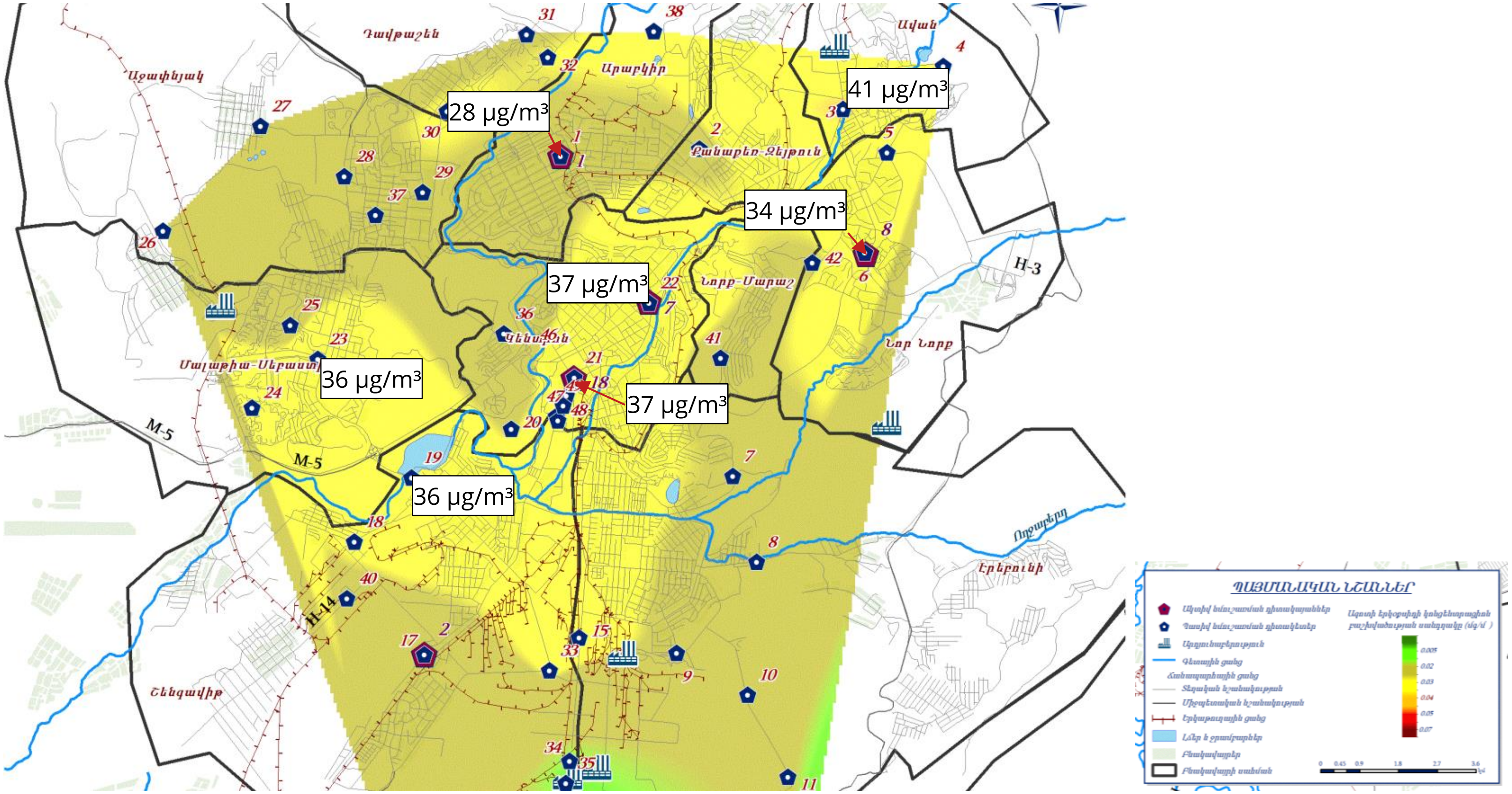
Figure 14 shows interpolated concentrations as well. However, due to the large variability of NO_2 levels at small scale, such interpolations shows merely general levels but do not allow identifying maximum concentrations. Figure 16 shows as an example a heavily trafficked road for which a passive sampling campaign and high resolution modelling was undertaken. It can be seen that due to open structure of buildings on the right side of the street, concentrations are considerably lower.

Figure 15 shows SO_2 passive sampling sites and selected annual mean concentrations for 2021. The spatial pattern is quite different from NO_2, which is to be expected due to the different main sources.

Nevertheless, it is recommended that commercial available passive samplers are exposed for some periods in parallel at some stations to validate the results of the passive sampling.

Figure 14: Location of NO_2 passive and active monitoring sites in Yerevan. NO_2 concentrations of 2021 at selected sites.

NO_2 passive and active sampling in Yerevan (2021 levels)

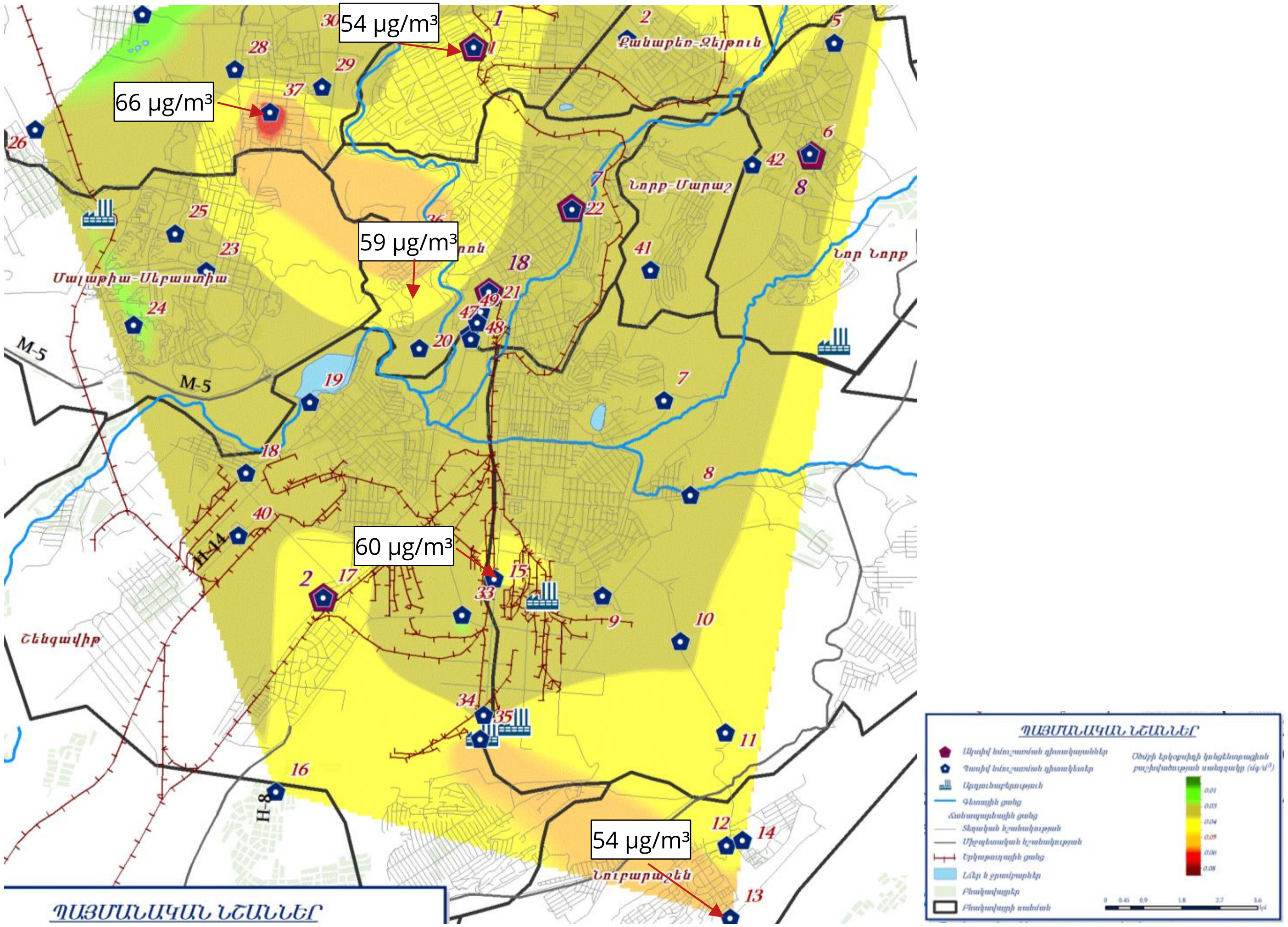


Source: HMC, Umweltbundesamt

umweltbundesamt

Figure 15: Location of SO_2 passive and active monitoring sites in Yerevan. SO_2 concentrations of 2021 at selected sites.

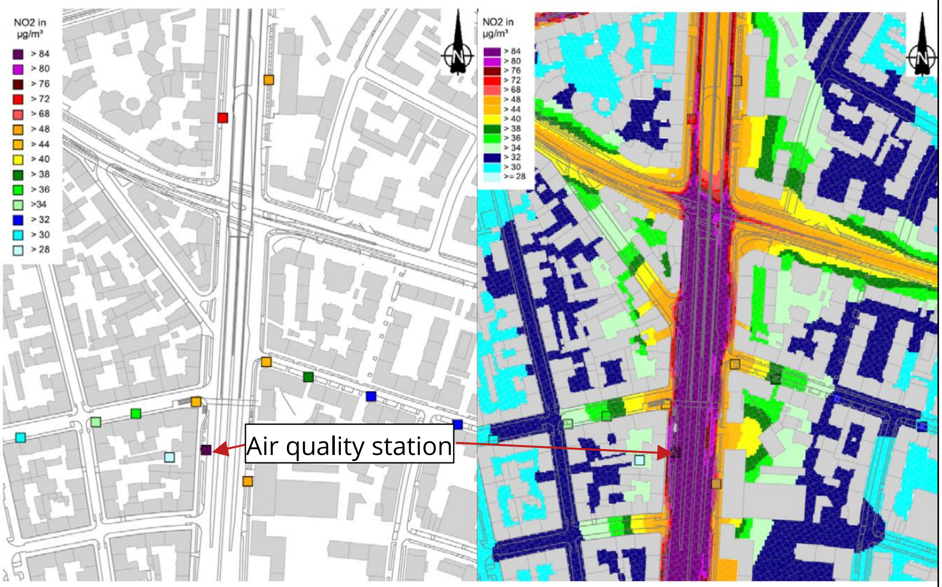
SO_2 passive and active sampling in Yerevan (2021 levels)



Source: HMC, Umweltbundesamt

Figure 16: NO_2 monitored (passive and one active site, left figure) and modelled concentrations around a heavily trafficked road in Munich.

NO_2 levels in Munich, Landshuter Allee

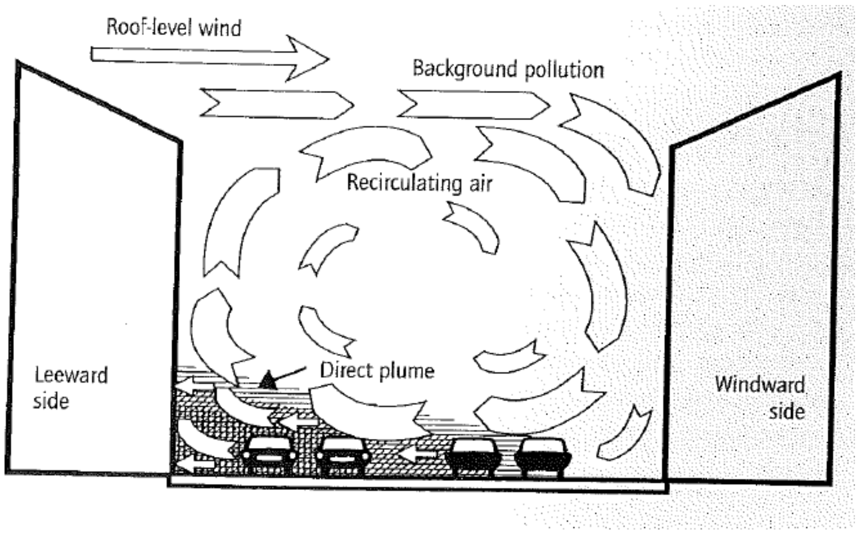


Source: (LfU 2015)

Figure 17 shows that even for pollutants emitted at street level, prevailing wind directions cause different pollutant levels at the leeward and windward side.

Figure 17: Distribution of pollutant concentrations dependent on wind direction.

Distribution of air pollutant concentrations in a street canyon



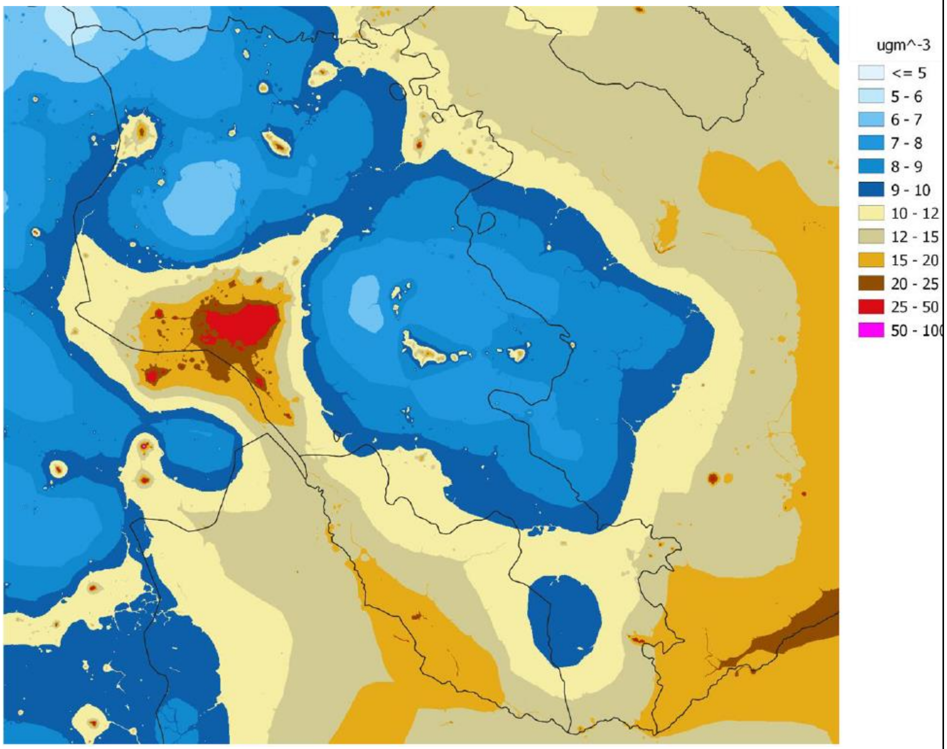
Source: (Hewitt and Jackson 2020)

6.1.3 Modelling data

At a recent meeting[19] within the UNECE Expert Panel on Clean Air in Cities results of air quality modelling of $PM_{2.5}$ for Armenian was presented (Denby 11/16/2022). It will be checked whether modelling results of other pollutant are available.

Figure 18: Modelled $PM_{2.5}$ concentrations of Armenia for 2015.

$PM_{2.5}$ annual mean 2015



Source: (Denby 11/16/2022)

umweltbundesamt

6.1.4 Topography and building densities

The large scale topography, especially valleys or basins, impacts the climate via wind patterns and inversions. Therefore, knowledge about topography is needed for selecting the location of the pilot stations. On a smaller scale, building height and building densities are crucial parameters for pollutant dispersion and accumulation, see Figure 16 and Figure 17.

No data for topography and buildings was yet made available.

19 https://previous.iiasa.ac.at/web/home/research/researchPrograms/air/policy/EPCAC_presentations_2022.html, last viewed on 30 November 2022

6.1.5 Meteorology

Meteorology impacts on pollutant levels. The main parameters necessary to interpret concentrations on air pollutants are wind directions, wind speed, and temperature inversions.

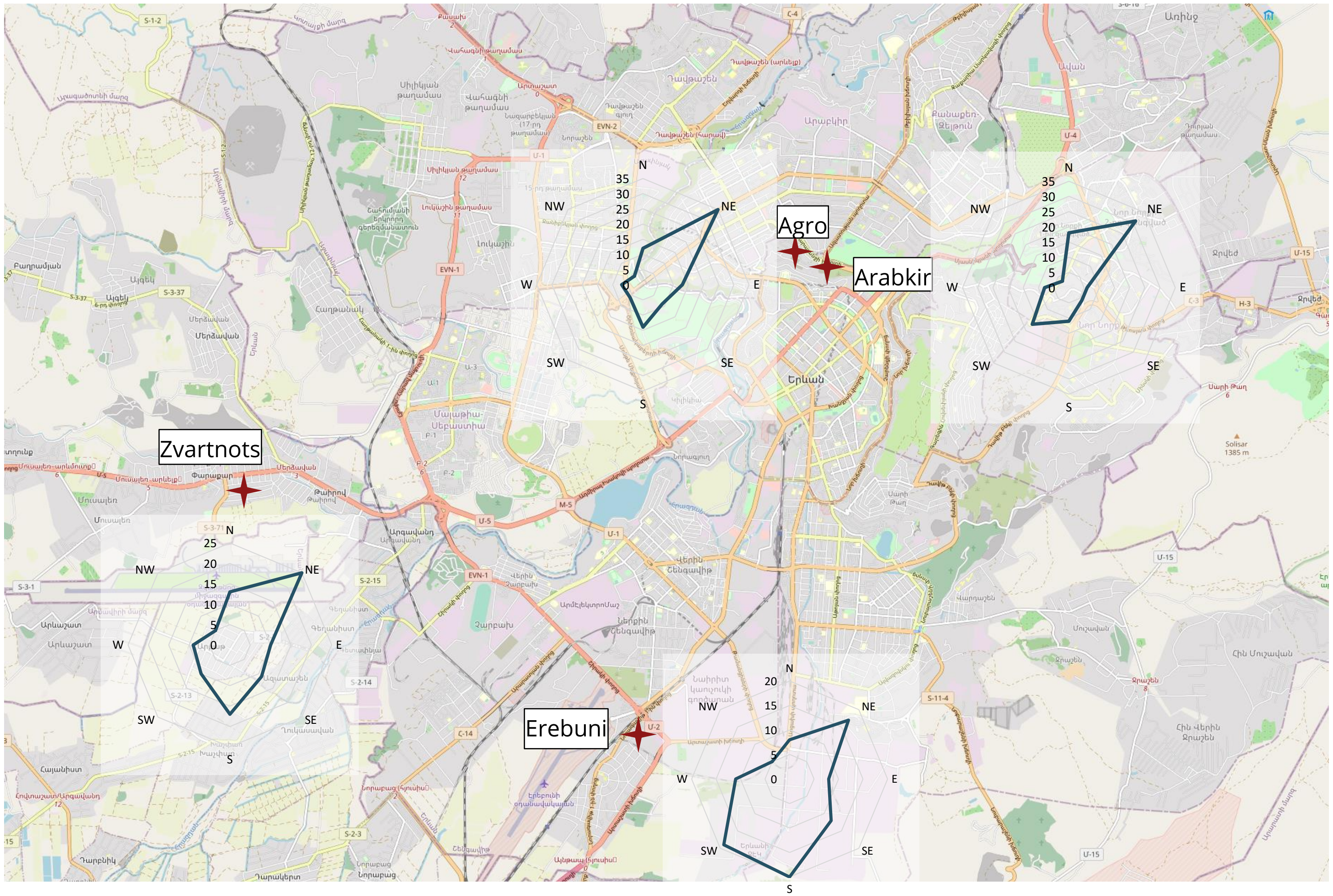
According to information by HCM based on workshop presentation, during winter, Armenia may be influenced by polar, and arctic (rarely) air masses which can be of both continental and maritime origins modified by continental influence (Gevorgyan et al. 2015). Intrusion of cold air masses from the north and maintenance of anticyclonic circulation are favourable conditions for the formation of strong surface inversions in closed basins and valley regions of Armenia such a Ararat Valley, Shirak plateau, etc. These synoptic-scale systems and the influence of topography make the winter circulation and the spatial distribution of precipitation, temperature and wind quite complicated in this region. A strong and persistent inversion was observed in Armenia in December 2013 causing low temperatures in inversion affected regions. Yerevan is located northeast of the Ararat Plain. The upper part of the city is surrounded with mountains on three sides while it descends to the banks of the river Hrazdan at the south.

Wind data was made available of four stations in Yerevan. According to this data, the main wind directions are North-East and South. There are however, large differences between the days with calms at these stations. Whereas at stations Erebuni and Agro there are around 200 calm days per year, at Arabkir there are only 80 days, at Zvartnots 135.

As stations Agro and Arabkir are rather close, these should have a similar number of calm days. The reason for this large difference should be clarified.

Figure 19 Meteorological stations and percentages of wind direction at these stations.

Meteorological stations in Yerevan



Source: HMC, openstreetmap

6.1.6 Traffic data

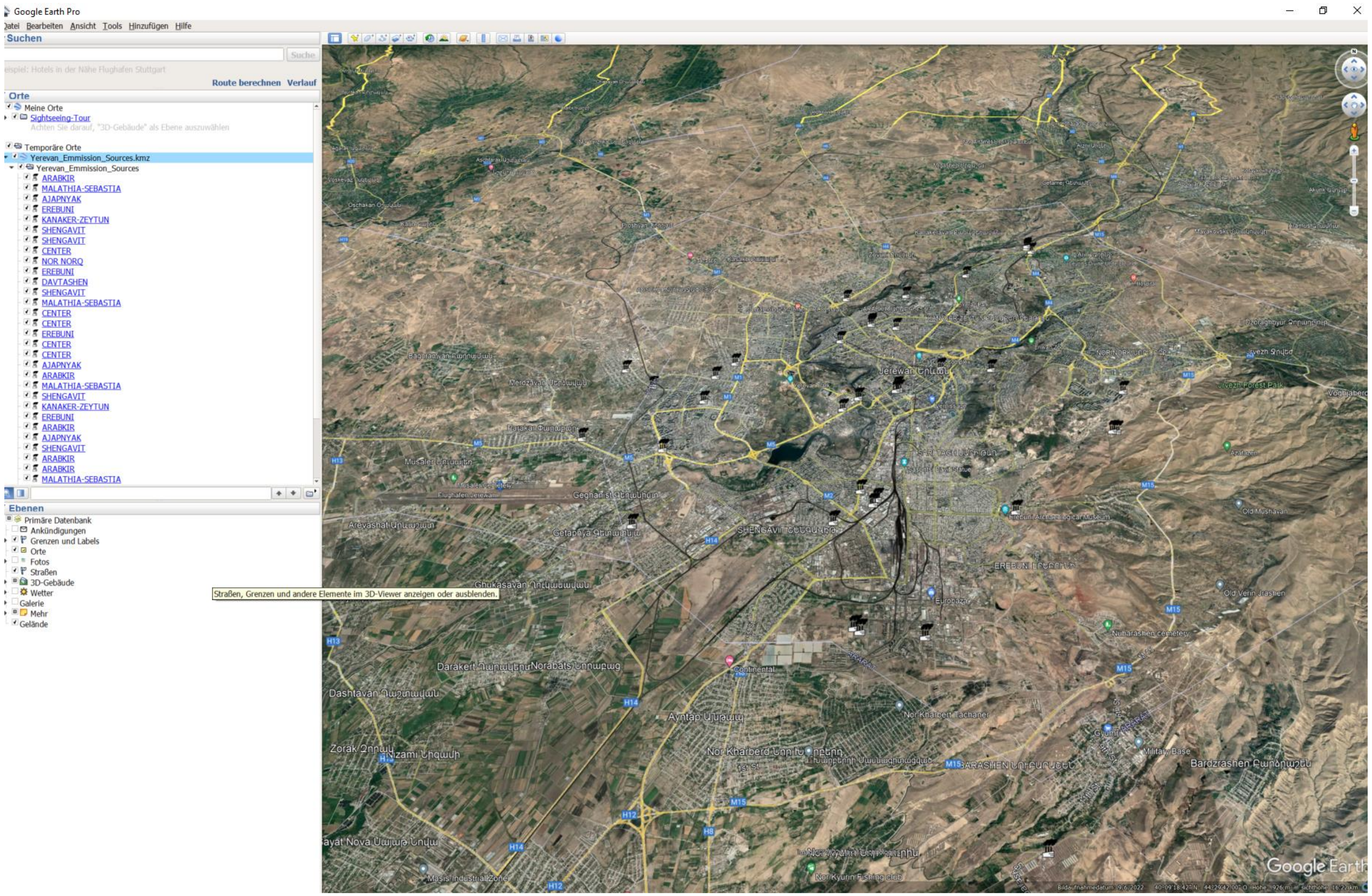
So far, no data about traffic could be provided.

6.1.7 Emissions

A list of facilities and of pollutants emitted by these facilities was made available (Figure 20). However, the amount of emissions was not included in that list.

Figure 20: Industrial facilities in Yerevan.

Location of industrial facilities in Yerevan



Source: HMC, Umweltbundesamt, Google Earth

umweltbundesamt

6.2 Implementation process

As described in section 6.1 crucial information is still missing to identify proper locations of the pilot stations and to expand the network further in future. This relates to traffic data, topography and building densities. Part of these date could be available from the Cadastre Committee, which will be contacted by HMC.

Therefore, the selection of suitable locations will be done together with the actual implementation within the EU4Env project within Outcome 2.3 in close cooperation with UNDP.[20]

The actual selection of these locations will be based on the criteria for air quality stations described in section 5.2 in discussion with HMC experts.

It is proposed that this is done in a two-step approach: first, possible areas for the stations are selected. In a second step the exact locations should be identified with the help of a passive sampling campaign within these areas at locations fulfilling the criteria and requirements for a station. Thereby a suitable location for a hotspot and an urban background station can be identified.

[20] https://eu4waterdata.eu/en/, last viewed on 8 November 2022.

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